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FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES

POWDER INJECTION MOULDING INTERNATIONAL

in this issue

Profiles: Element 22, CMG Technologies

MIM in China

Euro PM2013 conference review

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Powder Injection Moulding International

For the metal, ceramic and carbide injection moulding industries

New markets, new materials, and new opportunities

It's been another busy year for the *PIM International* team, having exhibited or been represented at more than ten industry conferences and exhibitions in 2013. Established international events such as the annual conference of the PM Association of India (PMAI), the conferences of North America's Metal Injection Molding Association (MIMA) and Metal Powder Industries Federation (MPIF), and the Euro PM event from the European PM Association (EPMA) continue to provide essential environments for networking and the exchange of information on developments in Powder Injection Moulding.

New international events are, however, reflecting the evolving nature of the industry. This year's Asian PM Association (APMA) conference in Xiamen, China, attracted a large number of regional and international delegates and exhibitors. This was the second APMA conference and there can be no doubt that future conferences in the series will become key events in the international industry calendar. The distribution of *PIM International* at such key events continues to be an invaluable way to reach out to new readers and we look forward to what promises to be a very busy World Congress year in 2014.

In this issue of *PIM International* we present an update on the evolution of MIM in China. To describe MIM's rise in China as dramatic risks understating the extent to which production has boomed in the last ten years. The Chinese industry is, however, one of stark contrasts between huge corporations and small low-tech start-ups and both extremes face distinct challenges (page 31).

At the cutting edge of MIM technology is Germany's Element 22, a company devoted solely to the commercialisation of MIM titanium. Dr Georg Schlieper recently visited the company to discuss the current status of the technology and the outlook for the coming years (page 39). We also profile the UK's CMG Technologies, formerly Egide UK, following a management buyout (page 59).

September's Euro PM2013 conference in Gothenburg, Sweden, offered a programme rich in PIM innovations. Our report on Euro PM2013 can be seen on page 47. As for the coming year, we look forward to banishing the winter blues with a visit to the MIM2014 conference in Long Beach, California, February 24-26. See you there!

Nick Williams
Managing Director and Editor

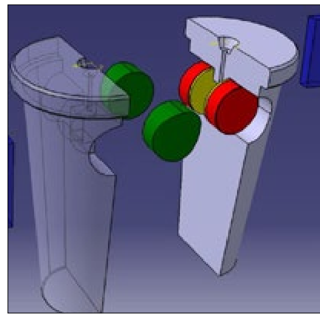
Cover image
Swann-Morton surgical handle manufactured by CMG Technologies, UK. Photo Swann-Morton

December 2013

Powder Injection Moulding International







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Regular features

Industry News

To submit news for inclusion in *Powder Injection Moulding International* please contact Nick Williams nick@inovar-communications.com

Maetta orthopedic MIM device receives FDA clearance

Maetta Sciences has announced that Food and Drug Administration (FDA) clearance has been obtained for a cobalt chrome orthopaedic implantable device manufactured using its proprietary MIM technology. This project was developed in close collaboration with one of the company's large OEM customers. The company stated that it planned to rapidly commence the production of this device for market introduction this autumn.

In March 2013 Maetta moved to a brand new 15,000 ft^2 manufacturing facility located in Varennes, on the south shore of Montreal, Quebec, Canada, where it already manufactures medical instrument and aerospace components. This investment was required to continue its expansion in both medical device and aerospace markets by adding additional space and equipment as well as implementing special process flows to comply with the specific requirements for implantable devices.

Serge Bragdon, Chairman of the Board, stated, "This announcement confirms the quality of the team and the thoroughness of the development process the company has put in place. Not only does our technology generate significant cost savings to our clients, it also yields superior material properties and process robustness."

Yvan Beaudoin, President and CEO, added, "It is a great achievement by our team as we believe this is the first time FDA clearance has been obtained for an implantable device made by MIM. It is also very encouraging as Maetta is currently involved in the development of several implantable devices with various clients."

The company holds ISO 13485; 2003, AS9100: 2009 and ISO 9001: 2008 certifications and is specialised in high end materials such as cobalt chrome, titanium alloys and nickel superalloys.

Maetta's MIM technology, states the company, combined with a sophisticated quality system, offers a distinctive proposition to industries such as medical and aerospace where there may be complex challenges such as small production volumes, highly complex shapes and stringent quality and regulatory requirements.

www.maetta.ca

Epson Atmix completes new fine powder plant

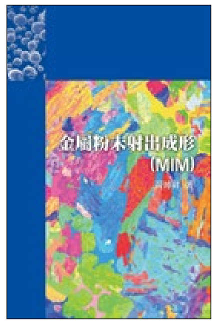
Seiko Epson Corporation announced in September that Group company Epson Atmix Corporation has completed construction of its new Kita-Inter Plant. Construction of the plant began in June 2012. Epson Atmix, which is located in Hachinohe-shi, Aomori Prefecture, Japan, is a leading manufacturer of superfine alloy powder. The new plant was scheduled to begin operations in October, tripling the company's manufacturing capacity for gas atomised superfine alloy powder for Metal Injection Moulding and magnetic applications.

Epson Atmix invested Yen 3.2 billion to triple its annual production capacity to 10,000 tons of superfine alloy powder. The company states that powder manufactured at the new plant will find applications in components for automobiles and medical instruments as well as sophisticated mobile devices such as smartphones and tablet PCs.

Epson Atmix states that it designed its new production lines to minimise energy and resources consumption. By carefully selecting and deploying production equipment for the new plant, the company succeeded in reducing CO_2 emissions by approximately 25% and waste emissions by approximately 50% compared to a production unit in the original plant. The plant has a floor area of approximately 3,300 m^2 on a 20,500 m^2 plot.

www.atmix.co.jp

New Chinese language MIM reference book published



The Taiwan PM Association (TPMA) has just released a new Chinese language book on Metal Injection Moulding (MIM). This new book, which offers a complete overview of the MIM process, has been written by Professor Kuen-Shyang Hwang. The book's fifteen chapters include powder manufacturing and characterisation, feedstock compounding, injection moulding, debinding, sintering principles and practices, secondary operations, alloy steels, stainless steels, non-ferrous metals, defects/production problems, and testing. Also included is a chapter introducing physical metallurgy for non-metallurgist readers.

It is stated that the author started writing this book two years ago when he considered the MIM market for Chinese readers was large enough to cover the publishing cost. The intention is to provide the MIM practitioners mainly in Taiwan and China with a reference for training and for troubleshooting. ISBN 978-957-97731-7-1

Megamet strengthens its management team with the appointment of Brian McBride

US MIM producer Megamet Solid Metals Inc., based in Earth City, Missouri, has appointed Brian McBride as Director of Operations. McBride was formerly General Manager of Parmatech Corporation, Petaluma, USA.

Bruce Dionne, Vice-President and General Manager at Megamet, told *PIM International*, "Brian brings with him a wealth of experience from one of the most well known MIM companies in the business. We are very excited that he has joined us at Megamet and look forward to working with him to manage the continuing and rapid growth of our business."

McBride told *PIM International*, "I'm thrilled to be able to bring a fresh perspective on the Megamet operation and to help the company continue to grow at the impressive rate that it has enjoyed in recent years. Our challenge is to continue to improve and refine both our manufacturing operations and our management systems here at Megamet as the business continues to evolve."

McBride is also serving as Co-chairman of the MIM2014 International Conference on Injection Molding of Metals, Ceramics and Carbides, taking place in Long Beach, USA, from February 24–26 2014.

www.megamet.com

Continuous and batch sintering lines at Megamet Solid Metals

GKN Powder Metallurgy sales up 13% in third quarter

Figures released in GKN plc's interim management statement show that the GKN Group made good progress in the three months ended 30 September 2013, with sales totalling £1,865 million, a 16% increase over the same period in 2012, including 6% organic growth. The increase in sales from acquisitions less divestments was reported as £145 million.

"The third quarter showed good progress, supported by automotive demand in China and North America and sustained high output levels in commercial aerospace. GKN Aerospace Engine Systems made a strong contribution to the Group's 34% growth in profit before tax," stated Nigel Stein, Chief Executive, GKN plc.

Third quarter sales in the group's GKN Powder Metallurgy division were up 13% to £234 million (2012: £208 million), with organic sales growth of 10%, outperforming automotive production in both Europe and North America, stated the report. Trading profit increased to £23 million (2012: £20 million) at a margin of 9.8% (2012: 9.6%).

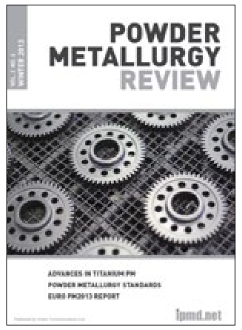
Year to date figures for GKN Powder Metallurgy were also up on the previous year with the first nine months sales totalling £714 million, up from £673 million in 2012.

The report stated that global light vehicle production in the third quarter, of around 20 million vehicles, was 4% ahead of the comparable period in 2012 with good growth in China (+9%) and North America (+6%) and more modest growth in Europe (+2%) and Japan (+2%). Brazil (+7%) and India (+5%) continued to be volatile.

Automotive and commercial aerospace markets are expected to remain robust with industrial and military aerospace markets soft, the company stated. The Group expects 2013 overall to show another year of good progress helped by the contribution of GKN Aerospace Engine Systems.

www.gkn.com

Powder Metallurgy Review: Winter 2013 issue out now



The latest issue of *Powder Metallurgy Review*, the magazine for the PM industry, has just been published and is available to download free of charge from www.ipmd.net.

This 72 page issue features a specially commissioned report on the developments in titanium Powder Metallurgy, as well as a major review of the development of PM standards worldwide. Technical highlights from Euro PM2013 and Japanese award winning PM parts are also covered. To download your free digital edition of *PM Review*, visit

www.ipmd.net/pmreview

Parmatech makes changes to management team

ATW Companies Inc., based in Warwick, Rhode Island, USA, has announced that Parmatech Corporation, its Metal Injection Moulded (MIM) components and services subsidiary, has made changes to its management team with a number of new appointments and promotions. The company stated that Rob Hall has been promoted to President of Parmatech; Jen Benoit has been hired as the Plant Manager at Parmatech Rhode Island facility, and Anita Shah has been promoted to Manufacturing Manager of Parmatech's facility in Petaluma, California.

Hall most recently served as the Operations Manager at the Parmatech operation in Petaluma where, stated ATW, he developed and executed an operational plan to meet company and corporate goals, thereby improving profit, throughput, and employee satisfaction. ATW added that Hall will use many of the skills he honed as Operations Manager in his new position as President of Parmatech/Vice President of MIM Operations. As the head of financial stewardship for Parmatech's combined California and Rhode Island operations, it was stated that he will work to optimise existing operational systems and support strategic customer relationships.

Jen Benoit was formerly the Assembly Manager for the M&P Pistol Line at Smith & Wesson. In this role she proved her skills as a manager, overseeing 90 employees and maintaining the assembly schedules for five different product lines. As the Parmatech Rhode Island Plant Manager she will be responsible for all aspects of the Rhode Island facility, including the manufacture of all products, customer support, and collaboration with feedstock production, engineering and quality systems from California.

Before her promotion to Manufacturing Manager of Parmatech California, Anita Shah was the Logistics Manager for Parmatech. ATW stated that Shah's excellent track record with managing information and resources helped to ensure consistent product quality and customer satisfaction, and the company believes she will continue to excel in her new position. As Manufacturing Manager, Shah's responsibilities will be expanded to include oversight over all aspects of the company's California-based manufacturing systems, such as raw material procurement, feedstock preparation, and production of moulded and sintered product.

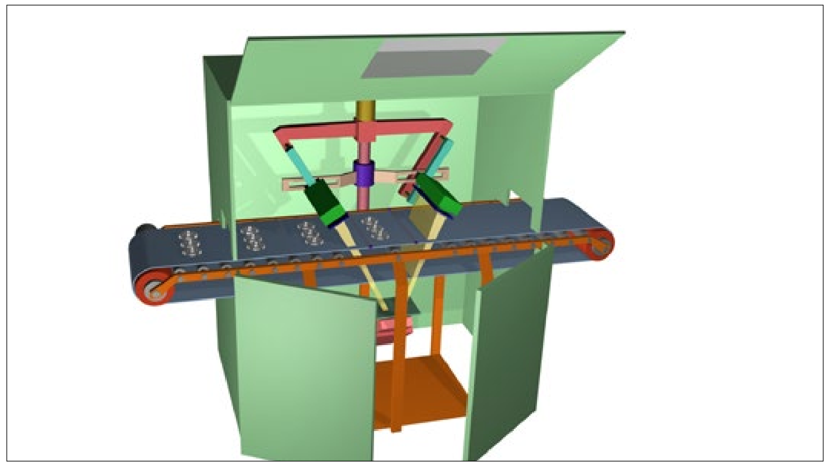
"By promoting talent through inside channels, Parmatech California and Rhode Island are being led by people who know the process, product, and customer," stated Tracy MacNeal, Chief Strategy Officer, "Combined, those are powerful tools."

"In addition, this sort of talent is ideal for optimising our cross-functional teams" MacNeal continued, "Teams in both locations are supporting the same strategic growth initiatives, and this growth will only be made possible by a shared focus on superior quality, accurate launch timelines, and the consistent cost savings provided by MIM. We are confident that these three will accomplish all that and more."

www.parmatech.com

AutoInspect consortium to demonstrate MIM inspection system

The AutoInspect consortium, a European Framework 7 (FP7) funded project, has developed a digital radiographic system for the real time inspection of Metal Injection Moulded (MIM) and Powder Metallurgy (PM) parts, both in the sintered and green state. This technique has been developed in order to detect small cracks, flaws and density variations in-line in parts produced in a factory environment.



AutoInspect is a digital radiography inspection technique which is able to inspect MIM and PM parts in seconds

The AutoInspect system is able to inspect MIM and PM parts in seconds. Embedded Time Delay Integration (TDI) linear X-ray detectors allow the supply conveyor to run continuously while a row of parts is simultaneously scanned.

The TDI technique creates very low noise X-ray images with resolution up to 10 µm pixel size, depending on X-ray set-up magnification. A dedicated image analysis algorithm for the automatic detection of defects with pre/post processing and an enhancement algorithm is used to determine good and bad components.

TWI Ltd, a consortium partner based in Wales, UK, hosted a prototype demonstration on December 12th at the company's premises in Port Talbot.

Partners in the AutoInspect project are:

- Accent Pro 2000 s.r.l
- MIMTech ALFA SL
- Polkom Badania
- InnotecUK
- TWI Ltd
- Brunel Innovation Centre
- Vienna University of Technology

www.autoinspectproject.eu

Carpenter signs agreement with UTC and announces new superalloy powder facility

Carpenter Technology Corporation has announced a multi-level agreement with United Technologies Corporation (UTC), through its Pratt & Whitney Division, which includes licensing technology associated with the production of superalloy powders and a long-term supply agreement. Carpenter also announced plans to build a new superalloy powder facility in Alabama, USA, directly opposite the company's nearly completed $518 million ultra-premium product manufacturing plant.

The superalloy powder facility is expected to begin production in late 2015. Once the facility is qualified by Pratt & Whitney following construction, Carpenter will supply Pratt & Whitney with superalloy powder for use in aircraft engines for up to 20 years. "The capital cost of this project falls within the annual $120 million capital spend guidelines that were previously outlined for the period following the completion of the main Athens plant," stated Tony Thene, Carpenter's Chief Financial Officer.

Global demand for superalloy powder is expected to grow substantially as aircraft engine temperatures increase. Carpenter's entrance into this market segment reflects its confidence in superalloy powder demand for additional applications such as those used in energy and additive manufacturing, stated the company.

In addition to the powder supply agreement, UTC's aerospace business units (Pratt & Whitney, Pratt & Whitney Canada Corp., UTC Aerospace Systems and Sikorsky Aircraft Corporation) have agreed to purchase alloy steel bar/billet, nickel superalloy billet, stainless bar/billet, and strip laminate products from Carpenter for a period of ten years.

www.cartech.com

MIM 2014: Programme now available

The MIM2014 International Conference on the Injection Molding of Metals, Ceramics & Carbides will be held at the Hyatt Regency, Long Beach, California, USA from February 24-26 2014. The event is co-chaired by Uwe Haupt, Arburg GmbH & Co KG, and Brian McBride, Megamet Solid Metals.

The conference is sponsored by the Metal Injection Molding Association (MIMA), a trade association of the MPIF and its affiliate APMI International. The objective of the event is to explore the latest advances in MIM, assist in the transfer of technology, and investigate new developments in the field of injection moulding of metal, ceramics, and carbides.

Immediately prior to the conference, on Monday, February 24th, a one day PIM tutorial will be conducted by Prof. Randall M. German, San Diego State University.

www.mpif.org

Centorr Vacuum supplies multiple furnaces to Dynacast's MIM operation

Centorr Vacuum Industries (CVI) has announced it will be building its sixth MIM-Vac M furnace in 2013, expanding its customer base for the Metal Injection Moulding market. This, stated the company, includes multiple furnaces for Dynacast International's new Metal Injection Moulding operation.

Dynacast is a global manufacturer headquartered in Charlotte, North Carolina, USA. In February 2013 Dynacast announced that it would be adding Metal Injection Moulding to its existing die casting operations that manufacture zinc, aluminium and magnesium components for a wide variety of industries. The addition of MIM as a manufacturing process means that it will expand its ability to produce small, complex components using a wider variety of metals, strengthening its commitment to producing higher quality, precision engineered components for its customers.

CVI has over thirty years of successful MIM furnace building experience. Its MIM business is primarily comprised of a smaller research-sized unit designed with a 2 ft^3 hot zone (12 in. x 12 in. x 24 in.) and a larger production size unit at 9 ft^3 with an 18 in. x 18 in. x 48 in. size hot zone, however other sizes are also available. The new MIM-Vac M (modular design) has a number of design improvements, states CVI, including advanced molybdenum hot zones with "wide-flow" gas-plenum retorts using Sweepgas™ technology for consistent gas flow dynamics over all parts. It has a compact furnace layout with construction on a structural steel base for fast installation and the easy hookup of all utilities, yet provides full access to major components for ease of maintenance, with no cumbersome panels to remove.

A Dry mechanical pumping system with CVI's proprietary T/P (trap-over-pot) binder condensing trap provides clean and efficient handling of MIM binders with a second large trap after the vacuum pump for improved process cleanliness. The use of advanced Molybdenum alloys (Lanthanated Moly and TZM) in the hot zone and retort offers excellent creep resistance, higher recrystallization temperatures and longer service life.

A MIM-Vac M furnace from Centorr Vacuum Industries

All systems include a flexible HMI design with CE certification and all MIM-Vac™ furnaces offer temperature uniformity better than +/- 5°C. They operate in partial pressures from 10 torr up to 750 torr of argon, nitrogen, or hydrogen gas using mass flow controllers for automated control.

www.centorr.com

Phillips-Medisize Metal Injection Moulding expansion complete with increase in continuous debinding and sintering capability

Phillips-Medisize Corporation has announced the completion of a significant facility expansion at its Metal Injection Moulding (MIM) plant in Menomonie, Wisconsin, USA. This expansion was driven by new business awards in both the company's medical device and commercial segments.

The capacity expansion focuses on the Metal Injection Moulding business which provides customers with complex, precision-shaped parts typically weighing less than 150 g. The addition will increase the facility's continuous debinding and sintering furnace capacity, enabling it to provide high quality parts at a faster rate for customers.

"Our Metal Injection Moulding capability offers our customers a unique, cost-effective solution by providing complex shapes, superior strength, and dimensional precision in a scalable manufacturing model," stated Matt Jennings, Phillips-Medisize President and CEO.

Jennings continued, "We have seen increased interest from our medical device customers to help them design for MIM in surgical device applications as they look for ways to reduce costs and improve quality versus machined parts. The facility's expansion will bring much needed capacity to continue providing the highest level of satisfaction to both our growing medical and commercial customers."

Phillips-Medisize is a leading global outsource provider of design and manufacturing services to the medical device and diagnostics, drug delivery and commercial markets. The company has annual sales of just over $500 million with 75% of the total revenue coming from drug delivery, medical device and diagnostic products such as disposable insulin pens, glucose meters, specialty inhalation drug delivery devices, single use surgical devices and consumable diagnostic components.

Phillips-Medisize Corporation features a list of blue chip medical device, pharmaceutical and commercial customers. The company partners with its customers to provide design and development services which accelerate speed to market of innovative products and then works with its customers to deploy advanced automated assembly and quality control technologies which reduce manufacturing cost while improving quality. The company states that its core advantage is the knowledge of its people to integrate design, moulding, and automation to drive low cost and high quality manufacturing solutions.

The company employs over 3,100 people in 14 global locations throughout the United States, Europe, Mexico and China. The company has two design centres in the US and one in The Netherlands.

www.phillipsmedisize.com

Taiwanese award winning HPM process offers cost savings for small precision parts

The Taiwan Powder Metallurgy Association (TPMA) announced winners of its "Innovation Awards" during the association's annual conference in August 2013.

One of the winners, MIM parts producer Taiwan Powder Technologies (TPT), received an award for its new High Performance High Density PM (HPM) process. Using fine ferrous powders and a pre-treatment process, conventional press and sinter process is applied to the powder to produce PM parts with MIM properties.

The Fe-Ni-Cr-Mo products presented have a sintered density of 7.6g/cm3, tensile strength of 1,800 MPa, hardness of 50HRC, elongation of 5%, and impact energy of 60J. Age hardened 17-4PH HPM parts with a density of 7.6g/cm3 were also presented, which are rarely seen in the PM industry.

Structural parts used in hand tools and gear sets have been in production at TPT since early 2013, as shown in Fig. 1. These parts had been produced using the MIM process and now replaced by HPM due to the cost saving of about 35% and better dimensional control due to less shrinkage during sintering.

www.tpttw.com.tw

Fig. 1 A new High Performance High Density PM (HPM) process is applied by TPT to produce PM parts with MIM properties

Smartwatches expected to open up new opportunities for MIM and CIM

The Metal Injection Moulding (MIM) and Ceramic Injection Moulding (CIM) industries have enjoyed almost two decades of uninterrupted success in the production of watch cases, with most leading watch producers now adopting Powder Injection Moulding (PIM) technology for ceramic, hardmetal, titanium and stainless steel watch cases, components and bracelet parts. Notable pioneers in this area were Swatch with its Irony stainless steel watch case and Rado with its hardmetal and black zirconia watch cases.

At the same time, the MIM industry has in recent years enjoyed dramatic growth in Taiwan and China as the result of demand for small precision MIM components in the tens of millions per month for smartphones such as the Apple iPhone.

These two huge markets now look set to come together in a new type of watch, the smartwatch, which could provide significant opportunities for cases and other components.

A smartwatch is wearable computer technology that is not just for timekeeping but is also capable of a wide range of functions from making telephone calls to navigation, taking photos, messaging and viewing alerts, to name just a few.

Sony was the first to introduce its Android enabled smartwatch to the market with its Smartwatch2, featuring black bezel 1.6 in. screen and a prominent Sony logo on the bezel. Samsung introduced its Gear smartwatch in 2013 which has a high quality camera embedded in the strap and also a black bezel. The Galaxy Gear currently only connects to specific Samsung products, which limits its appeal to the wider Android market. Qualcomm will introduce its Toq smartwatch in December 2013, and like the Sony and Samsung devices, will also link to Android handsets to deliver incoming information to your wrist. Apple is reported to be developing an iWatch which is expected to come onto the market in the second half of 2014. Apple has filed 79 patents related to its smartwatch technology.

Market research group Canalysis estimates that some 500,000 smartwatches will have been sold in 2013, and that this figure could rise to over five million in 2014 if the iWatch is introduced to the market. This figure is expected to exceed 22 million in 2015 and 75 million in 2016. There are unconfirmed reports that both Apple and Qualcomm may use MIM technology to produce their smartwatches.

Google has taken another route to wearable computer technology with its Google Glass. This is a wearable Android-powered computer built into spectacle frames so that you can have a transparent display in your field of vision, film, take pictures, search and translate on the go as well as run specially-designed apps. Google Glass is designed to be lightweight and as unobtrusive as possible. The frame will come with adjustable pads for comfort, and is expected to be both light and extremely robust. It will also have a touchpad along one arm for silent interaction.

ARC Group announces record quarterly earnings and appoints new Chief Financial Officer

ARC Group Worldwide Inc., DeLand, Florida, USA, has reported net revenue of $18.4 million its first quarter fiscal 2014 results for the period ending September 29, 2013. Record adjusted EBITDA of $3.4 million, and net income of $1.3 million, were also announced. ARC also reported record adjusted earnings per share (Adjusted EPS) of $0.34 for the first quarter fiscal 2014. The first quarter results, it was stated, were driven by improved performance in its manufacturing operations and higher sales revenue resulting from the reverse acquisition between ARC and Quadrant Metals Technologies (QMT), and the acquisition of Advanced Forming Technology, Inc. (AFT) and AFT-Hungary Kft., (AFT-HU).

Jason Young, Chairman and CEO, stated, "I am pleased to report outstanding quarterly results that reflect continued growth in revenue, cash flow, and earnings per share. As the leader in Metal Injection Moulding and other niche manufacturing businesses, we continue to focus on building our market position in these areas, both organically and through acquisitions." He further added, "We are also focused on bringing technology and innovation to manufacturing. We have made good progress utilising 3D printing and view it to be a key area of future growth for ARC in production and prototypes."

The company's first quarter results stated that net revenue for the first quarter of the fiscal year 2014 increased 38.1% to $18.4 million, compared to $13.3 million in the prior year period. The QMT and AFT Acquisitions, which closed during the fiscal year 2013 period, contributed $2.9 million in additional sales. Excluding the impact from the aforementioned acquisition, sales growth still increased $2.2 million, or 16.3% compared to the prior year period. This increase is primarily the result of robust growth in our MIM businesses, the company stated.

ARC stated that it is committed to continuing to grow its MIM business as well as strengthen its market position in its core manufacturing businesses in glass-to-metal seals, flanges, fittings and wireless equipment. The company focuses on utilising technology and innovation, such as automation, robotics and 3D printing in order to help achieve its goals. ARC stated that it is also seeking out vertical and horizontal acquisitions in order to bolster its market position. In addition to making acquisitions that are strategic to ARC's core business, the company evaluates new manufacturing niches that fit into its broader objectives.

In October ARC Group announced the appointment of Drew M Kelley as the new Chief Financial Officer, replacing Norma Caceres. The company stated that Caceres will continue in a leadership capacity in the finance and accounting department of the QMT Metal Injection Moulding businesses.

Commenting on the changes, Young stated, "We thank Ms Caceres for her service as CFO of ARC as we transitioned the business." He further added, "We are very pleased to welcome Mr Kelley to ARC. Mr Kelley has an excellent corporate finance and capital markets background, having worked in leadership roles at several major Wall Street investment banks. His background will be instrumental as we utilise acquisitions and capital markets to fuel part of our future growth. We feel fortunate to have Drew join us at this stage and look forward to his role in helping us build ARC."

ARC group stated that Kelley brings a wealth of experience in equity and debt placements as well as mergers and acquisitions. Kelley was most recently a Senior Vice President at Jefferies LLC, a major Wall Street investment bank.

The ARC Group also recently launched its new website, www.arcgroupworldwide.com. Commenting on the new website, Young stated, "We are excited to launch our new website, which clearly and simply lays out ARC's capabilities, strategy and culture. We hope our new website is a helpful resource for our shareholders, customers, employees, and current and future partners."

www.arcgroupworldwide.com ■

CSIR signs titanium powder research MoU with Boeing

The Council for Scientific and Industrial Research (CSIR) in Pretoria, South Africa, has signed a memorandum of understanding (MoU) with the giant US aerospace group Boeing to cover joint research into using titanium powder in industrial manufacturing. "There are a number of building blocks we are developing to establish a South African titanium industry. One of these is aerospace," said Boeing International VP Africa Miguel Santos. "Working together, we expect to, one day, develop new technology using titanium powder," he said.

CSIR launched its pilot plant to produce titanium powder in the summer using its new patented manufacturing process. The aim of the pilot plant is to test and evaluate technologies developed by the CSIR that, it is anticipated, will produce titanium powder significantly more cheaply than existing processes, and in a continuous manner and not, as now, in a batch process. "You can go from titanium powder to titanium products. But titanium powder is rather expensive to produce. We believe we will have a lower cost process," explained Dr Van Vuuren, CSIR Materials Science and Manufacturing unit research group leader.

CSIR is aiming to build a semi-commercial titanium powder plant having a capacity of 500 tonnes/year by 2017 with an industrial partner. Successfully creating an economically competitive titanium powder production industry in South Africa is estimated to be worth between $3 billion and $5 billion to the economy. But it would also open the way for the establishment of an industry using titanium powder in Additive Manufacturing and Metal Injection Moulding to manufacture high-quality components for the aerospace and other high-tech industries.

Science and Technology Minister, Derek Hanekom (right) and CSIR CEO, Dr Sibusiso Sibisi at the official opening of the Ti powder pilot plant

www.csir.co.az ■

Taiwanese mould maker expands to meet growing international demand

Hua Cheng Moulding Co., Ltd, a manufacturer of precision moulds for the Powder Injection Moulding and Powder Metallurgy industries, has announced the opening of a new production facility in Miaoli County, Taiwan. The new site will employ around 100 people and focus on the manufacture of precision moulds for various applications.

In addition to the new production facility, Hua Cheng Moulding has invested in new high precision CNC machines from leading European manufacturers to duplicate the production capacity and technology of the company's Changshu facility. The investment includes Agie Charmilles EDM & WEDM, Carl Zeiss CMM, Makino Milling and Mikron High-Speed Milling.

Hua Cheng Moulding Co., Ltd was established in 1978 and offers a range of mould manufacturing options to both Asian and international customers. The company can produce moulds to ISO 9001 certification. Tools are made from Crucible, Böhler or Uddeholm steels or tungsten carbide with local equivalent steels and carbides also available if required.

David Lemon, Hua Cheng Moulding's European agent, stated, "Hua Cheng can offer a cost effective alternative for the production of advanced moulds for MIM, CIM and PM applications. As well as providing a competitive lead-time, their experienced and knowledgeable engineers can help optimise mould design and extend tool life through material selection and 'design for manufacture' principles."

Hua Cheng is actively promoting itself to markets in Europe, USA and Asia. "The new facility is in response to growing domestic and international demand. Our philosophy is to focus on providing economic, high precision products with short lead-times" stated Lo Yuan Feng, President of Hua Cheng Moulding Co., Ltd.

www.moldmaker.com.tw

Call for Papers issued for Euro PM2014 conference

The Euro PM2014 International Conference and Exhibition will be held in Salzburg, Austria, September 21 – 24 2014. Organised by the European Powder Metallurgy Association (EPMA), the event will host a programme of over 250 oral and poster papers that will cover all aspects of Powder Metallurgy, including:

- Powder Injection Moulding
- Additive Manufacturing
- Hard Materials & Diamond Tools
- Hot Isostatic Pressing
- New Materials and Applications
- PM Structural Parts

A Call for Papers has been issued, with the organisers requesting that abstracts are submitted on-line no later than February 5, 2014. In addition to the main technical programme there will also be a number of special interest seminars and workshops.

www.epma.com

Change of management at Schunk and ceremonial farewell for Gerhard Federer

The Schunk Group, based in Heuchelheim, Germany, celebrated its 100th anniversary this year with a variety of events and festivals taking place all over the world. As part of the Group's concluding anniversary celebration on October 17, CEO Gerhard Federer, who has retired for health reasons, received a ceremonial farewell.

Gerhard Federer, who announced his resignation in April 2013, has worked as part of the board of management of the Schunk Group since 2003 and became the CEO in 2007. "It is extremely hard for me to leave Schunk, but dealing with significant health problems and leading a company with over 8,000 people just cannot be done together for a long period of time," stated Federer.

Dr Arno Roth, who has been a member of the management board since 2007, was announced as Federer's successor and began his position on November 1, 2013. "I am excited to take on the great challenge of leading such an internationally active corporation. It will be an exciting and fulfilling task to get involved in even more different markets and cultures," stated Dr Roth. Dr Roth will be the CEO for the Sinter Metals Division as well as being responsible for the areas of personnel, finances, strategy development, public relations work, and investment controlling on the corporate level.

From left to right: Dr Heinz-Joachim Mäurer, Dr Arno Roth, Peter Manolopoulos and Gerhard Federer

Peter Manolopoulos also started work on November 1 as Roth's successor and will be responsible for the divisions of the Weiss Group and Sonosystems. Since 2002 Manolopoulos has held several leadership positions with the GEA Group AG, his last position there being the CEO of GEA Energietechnik GmbH. In 2011 he switched to Roth & Rau AG to work as part of the board of management for operative business.

The three-person management board is completed by Dr Heinz-Joachim Mäurer, who will continue to be responsible for the Materials Division, which produces carbon, graphite, carbon fibre-reinforced carbon, silicon carbide, aluminium oxide and quartz.

www.schunk-group.com

Tosoh increases shipments of zirconia

Tosoh Corp., Tokyo, Japan, is a leading supplier of zirconia powder and the company's Specialty Group reports that it significantly increased shipments of the ceramic material in 2013 following expansion of production capacity in 2012. The major uses for zirconia are for dental materials such as crowns and bridges, grinding media, fibre-optic connector ferrules, fuel cell components and automotive oxygen sensors. A black zirconia compound has been used to manufacture high-end covers for mobile phones, watch cases as well as wear parts for robotic optical systems

Whilst Tosoh produces what it claims to be a superior zirconia powder for the general market, it also manufactures complicated zirconia products such as ferrule blanks by PIM at its subsidiary Tosoh Ceramics Ltd. The PIM ferrule blanks have been in production since 1988. Critical to the quality of the ferrule blanks is the PC (Physical Contact) end of the PIM blank, the concentricity of the V-cone (fibre entrance) end the straightness of the tube, and the degree of cylindricity. The powder grade TZ-3Y-E is used in the PIM ferrule blanks.

In 2001 Tosoh also starting offering its high-purity zirconia PIM technology to the general market with 'off-the-shelf' feedstocks. Three compounds are currently offered, each compound being composed of high-purity zirconia powders and a proprietary binder formulation (approx. 50 vol %) developed for the intended debinding environment.

www.tosoh.com

Low cost energy efficient route for titanium powder

Case Western Reserve University (CWRU) in Cleveland, Ohio, USA, has received funding from the US Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) to further develop a new low cost, energy efficient method for extracting metal titanium from ore. "Our one year project, if successful, will lower the cost of titanium by up to 60%," stated Rohan Akolkar, Associate Professor of Chemical Engineering and the principal researcher on the project. Akolkar's team, which also includes Uziel Landau, Professor and Chair of Chemical Engineering, and Mark De Guire, Associate Professor of Materials Science and Engineering, will work towards demonstrating feasibility of their idea in the next year.

The CWRU team proposes to use an electrolytic process, called electrowinning, to directly extract titanium from molten titanium salts. A specialised electrochemical reactor will be designed and built at CWRU to facilitate a stable electrowinning process to produce the metal.

"Much of the cost associated with extracting titanium via conventional non-electrolytic routes lies in processing the sacrificial reducing agent, which is typically magnesium. In our direct electrolytic process, magnesium is not required," Akolkar said. "This reduces cost, reduces energy consumption and simplifies the overall process." The electrolytically extracted titanium is expected to contain fewer impurities and therefore have superior mechanical properties as extracted.

www.case.edu

Dynamic Group adds new equipment to keep pace with demand

The Dynamic Group, based in Ramsey, Minnesota, USA, has been an established producer of integrated tooling and injection moulding solutions for a number of decades including tooling for the Powder Injection Moulding sector. The group reports that several new machines have been added this year to keep up with growing demand. Recent additions to the mould manufacturing facilities include a Makino E33 CNC mill and an Agie Charmilles Cut 2000 Wire EDM. Dynamic has also added a laser engraver for steel marking and a scope for precision inspection. Numerous robotic work cells allow the company to offer its customers competitive lead times without sacrificing quality.

Moulding operations have been expanded with the addition of a Toshiba 55 ton electric press. The company states that it has developed highly specialised knowledge relating to MIM and CIM moulds for processing a wide array of powder feedstock including gold, copper, steels, aluminum, titanium, carbide and ceramics.

The Dynamic Group's moulding division also tests and qualifies the moulds it builds, so it understands the materials and mould design requirements involved. The group produces green parts but does not claim to be a MIM moulder because it does not debind and sinter in-house.

www.dynamicgroup.com

BioBone Research Network looks to CIM for promising candidate components for osseointegration

The four year BioBone Research Network (2012-2015) funded by the Marie Curie Initial Training Network (ITN) under the EU's FP7 Research Programme is looking at ceramic materials for bone substitution. Due to their unique properties, ceramics for bone substitution and engineering have been expanding recently, making inroads in high volume applications such as dental or orthopaedic implants.

The BioBone Network brings together ten partners in eight EU countries to pool resources in order for ceramics to reach their full potential. This work will require new scientists and engineers with multidisciplinary backgrounds incorporating fields as diverse as materials science and engineering, orthopaedics, tissue engineering, biology, chemistry and biomedical engineering. The ultimate objective of the BioBone Network is therefore to train young researchers to fill this demand in the strategic area of bioceramics for bone repair.

One of the partners in the BioBone ITN project, CeramTec, based in Plochlingen, Germany, stated in a recent mid-term report that it is using Ceramic Injection Moulding (CIM) to develop components with different surface features and structural properties, and that CIM can produce promising components for osseointegration.

This research has sought to establish which ceramic materials were suitable for feedstocks, and to adapt the CIM process from feedstock to the final sintered part. Work has focused on two different approaches: to create a dense material with a surface feature for cell culture and/or bone anchorage, and to create a porous material with an interconnected porosity suitable for cells and/or fluids circulation.

BIOLOX Delta® and yttria stabilised zirconia ceramic materials were chosen for their improved strength and toughness, but other materials can also be used depending on further development. Results have shown that whilst Ceramic Injection Moulding is a delicate process, with proper control of parameters good quality components could be achieved with a high level of reproducibility. Particular care was given to the thermal treatments such as debinding and to the mechanical and structural characterisations of components between and after each process step.

It was found possible to generate several kinds of surfaces with roughness ranging from 0.13 to 1.56 µm, and to also create dense samples whose volume was modified during injection (holes, geometrical shapes, etc). Porous ceramics were obtained through the use of a pore forming agent, which was burned out during debinding. However, even though CIM allowed the production of porous ceramics, further research is needed on the shape and size of such porosities. Finally, a new development area opened the way to two-component CIM, and the possibility to yield a porous layer on a dense ceramic in a one-step process.

www3.imperial.ac.uk/biobone

ExOne reports $11.6 million of revenue in third quarter 2013

The ExOne Company, a global provider of Additive Manufacturing /3D printing machines and printed products, has reported a 36% increase in revenue in the third quarter 2013, compared to the same period of 2012. ExOne stated that the growth was due to strong machine sales during the period, driving revenue to $11.6 million, up from $8.5 million for the third quarter of 2012.

ExOne's business primarily consists of manufacturing and selling 3D printing machines and printing products for its customers using its in-house 3D printing machines. The company offers pre-production collaboration and prints products for customers through its seven production service centres (PSC) which are located in the United States, Germany and Japan. ExOne builds 3D printing machines at its facilities in the United States and Germany.

Revenue for the nine-month period ended September 30, 2013 was $28.8 million, up $12.9 million, or 81%, compared with the prior year period, driven primarily by machine sales as well as growth in PSC revenue globally.

"We continue to aggressively execute on our stated strategic plan – increasing machine sales, expanding our production capacity and PSC network, and building our material and binders portfolio," stated S Kent Rockwell, Chairman and CEO of ExOne.

www.exone.com

New MIM operation set to expand the market for MIM parts in Finland

Plastoco Oy Ab, a manufacturer of technical plastic parts based in Porvoo, Finland, has expanded its operations to include Metal Injection Moulding. The family owned business has thirty years of experience in plastic injection moulding, primarily for the electrical and electronic industries, as well as mould design and mould manufacture capabilities. Sales of more than €3 million were achieved in 2011.

The company's plans for a full MIM production line date to 2012 when it commissioned the newly designed two unit MIM-ECO debinding and sintering furnace system from Elino Industrie Ofenbau GmbH, Germany. Plastoco is the first company to have installed this system worldwide (see *PIM International* Vol. 7 No. 3 86-90 for a technical report on this system).

Commenting on the reasons for the company's move into MIM technology Jari Tahvanainen, Project Manager MIM at Plastoco, told *PIM International*, "Expanding to MIM production came to us partly through customer requests. We needed to widen our material selection so that we could offer solutions when the mechanical properties of plastic are not good enough. Our customers were interested in this process and its possibilities, so this was a key motivation when considering this expansion. We also undertook a market survey to map out the potential for MIM parts usage in Finland."

Expansion into MIM presents a new set of challenges for plastics producers. Tahvanainen explained, "The biggest challenges were selecting the new furnaces and understanding their processes. We were keen to find a reliable manufacturer and select the right technology for to allow us to produce high quality MIM parts from the start, as well as to be sure that the debinding process was carried out in the safest way possible. We had great help from our injection machine supplier Arburg GmbH & Co KG regarding these challenges and then selection of the furnace supplier was done through detailed investigation of all key suppliers and their proposals. Mould technology and injection moulding was relatively easy for us because of our background."

Commenting specifically on the selection of the new Elino twin batch furnace system, Tahvanainen told *PIM International*, "The biggest factor for us was getting the latest and newest technology. Our new two unit MIM furnace system is the first one of its type in the world and it gives us technical advantages in terms of maintenance and economy. Elino's good customer service also had a big impact and they were the only supplier interested to visit us during the quotation phase. We have been very pleased with our furnace system, particularly the maintenance free sintering furnace, which is a very big advantage, and Elino's response to technical issues has been excellent."

Plastoco selected BASF SE's Catamold feedstock system for its MIM operation, commenting that the close cooperation between Arburg and BASF was an important factor. The company is currently processing 17-4PHF, 316 LA and 316L G feedstocks. "This range will of course widen

Fig. 1 The injection moulding area at Plastoco Oy Ab. Two Arburg injection moulding machines have so far been adapted for MIM

Fig. 2 The two unit debind and sinter system at Plastoco Oy Ab. At the rear of the photograph is the Elino MIM Eco debinding Unit CT 050-085 and at the front MIM Eco sintering Unit VR 050-145, capable of sintering at up to 1450°C

if needed by customer request. We already have some experience from M2 tool steel and we have made trials with materials such as 42CrMo4, 100Cr6 and 440Nb."

The company currently operates two injection moulding machines that have been modified for MIM, a 35 ton and 50 ton machine. Modifications included a new screw and additional equipment for the safe handling of fragile green parts. Commenting on potential markets and regions for the company's MIM business Tahvanainen stated,"Our main market area will be Finland, however we are already exporting to Sweden and are ready for further expansion – perhaps Northern Europe or even further if needed. Applications will be mostly machine and equipment manufacturers, such as locks and medical industry. We see great potential for MIM parts."

Tahvanainen recognises that a lot of work still has to be done to increase awareness of MIM in Finland stating, "Some know it quite well, but on average knowledge about MIM has been very low. We have distributed information to all our current key customers and also all potential

Fig. 3 The tooling workshop at Plastoco Oy Ab. The company has many years of experience in the design, manufacture and maintenance of injection moulding tooling

Fig. 4 MIM parts manufactured by Plastoco Oy Ab

Fig. 5 MIM parts manufactured by Plastoco Oy Ab

customers and we have had several companies visiting us in order to get more information about MIM and to see our new furnaces."

Commenting on the anticipated types of parts and order sizes Tahvanainen stated, "This depends heavily on the weight and size of part. But roughly order sizes will range from 1000 – 200,000 parts per year. Our furnace isn't the smallest one so we have quite a lot of capacity to offer."

For more information contact Jari Tahvanainen, email: jari.tahvanainen@plastoco.fi or visit www.plastoco.fi ■

Submitting News

To submit news to *Powder Injection Moulding International* contact Nick Williams: nick@inovar-communications.com

Review highlights progress in titanium MIM

The production of titanium components by Metal Injection Moulding has been the subject of much effort over the past couple of decades, states Professor Randall M. German (San Diego State University, California, USA) in a review published in Materials (Vol. 6, August 2013, pp 3641-3662).

In the review Prof Geman covered the development of titanium and titanium alloy powders suitable for MIM, and the effect of interstitial oxygen, carbon, nitrogen and hydrogen on properties, with emphasis on how oxygen content levels impact on tensile and yield strength. Alloying and microstructures are also covered as are the development of Ti-MIM applications in areas such as dental, aerospace, medical and chemical devices. Prof German stated that whilst variants of Ti-MIM processing are being used by several companies around the world to manufacture Ti-MIM components commercially, the total annual sales value is estimated to be only around $10 million, equating to approximately 10 metric tonnes.

The major issue for MIM producers is said to be the high cost of titanium powders. Standard titanium powder grades with low interstitial levels are in the range of $110 to $220 per kg depending on quantity, interstitial level, alloy, and particle size. For MIM grade titanium powder, which can be highly variable with respect to particle size, purity and alloying, the price can be as high as $600 per kg, stated Prof. German. He indicated that there were at least fifteen efforts underway to produce a low cost, high purity titanium powder, but to date significant difficulties have arisen in scaling up manufacturing even to pilot plant scale. In the short term the Ti-MIM community will continue to rely on standard current grades.

www.mdpi.com/journal/materials

Verder Group acquires furnace manufacturer Gero

Gero Hochtemperaturöfen GmbH & Co. KG located in Neuhausen, near Stuttgart, Germany, has recently been acquired by the Verder Group, joining the company's Scientific Division.

Gero manufactures a wide range of furnaces for a number of applications including Powder Metallurgy and Metal Injection Moulding. Furnaces are suitable for both industrial and research processes, with models capable of operating up to 3000°C. The company generates a turnover of some €7 Million.

"With the acquisition of Gero, the Scientific Division of the Verder Group now offers the complete range of high temperature furnaces up to 3000°C," stated Dr Jürgen Pankratz, Director of the Verder Scientific Division. "Gero's portfolio complements the line of laboratory and industrial furnaces and ovens offered by the British manufacturer Carbolite Ltd., also part of the Verder Group."

www.gero-gmbh.de

PIM used to produced toughened and functionally graded cemented carbides

The Metal Forming Group at the Singapore Institute of Manufacturing Technology (SIMTech), a research institute of the Agency for Science, Technology and Research (A*STAR), has been undertaking a research project aimed at producing high performance tungsten carbides with the cobalt binder content reduced to less than 3%.

WC-based carbides with lower Co concentrations show high hardness but poor toughness, and the researchers at SIMTech have studied the possibility of in-situ toughening of WC by making use of abnormal grain growth (AGG) of tungsten grains to reinforce WC-Co by the PIM process.

Silicon carbide or silicon nitride grains were used as the in-situ reinforcing agents and to achieve AGG. AGG could be controlled by the composite composition and processing conditions, which allowed in-situ toughening of the cemented by tailoring the abnormal grains in the composite. Functionally graded WC-Co composites were also produced by PIM.

The Metal Forming Group has also developed a self-pressure sintering process (1800°C for 90 min) to reduce porosity in the in-situ formed WC-Co composite material. The pressure is said to be generated due to the difference in shrinkage of the base carbide and the ceramic reinforcing agent. The result is an in-situ formed WC composite with improved toughness compared to the brittleness of the conventional WC-Co with low Co content. Potential applications include nozzles used in electronics, cutting tools, and punch tools for metal stamping.

For more information contact: Li Qingfa, qfli@SIMTech.a-star.edu.sg

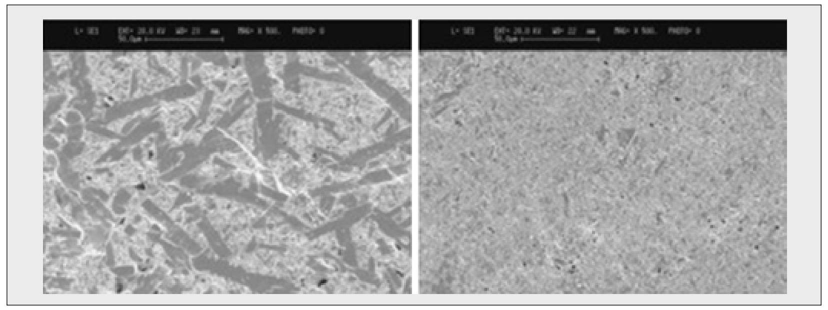


Fig. 1 Abnormal grain growth (AGG) and grain growth inhibition in in-situ formed WC-Co composite

New Additive Manufacturing conference to run alongside PM2014 World Congress, Florida

The Metal Powder Industries Federation (MPIF) has announced its inaugural conference on "Additive Manufacturing with Powder Metallurgy" (AMPM) will take place May 18 - 20 2014, in Orlando, Florida, USA.

This new conference will run alongside the PM2014 World Congress on Powder Metallurgy & Particulate Materials and the Tungsten, Refractory & Hardmaterials Conference, taking place at the same venue.

Co-chairmen Gregory Morris, GE Aviation, and Joseph Strauss, HJE Company, Inc., anticipate that presentations will include the perspective of metal powder producers, toll providers and end-users of AM processes, R&D programs from academia and consortiums, and equipment manufacturers. Expected topics will include materials, applications, technical barriers, process economics, and new developments.

www.mpif.org

Metal Injection Moulding in China: An overview of current status, opportunities and challenges

The past decade has seen the production of MIM components in China grow at a dramatic and unprecedented rate. This growth has been driven in part by 3C applications for international OEMs and in part by domestic applications such as medical devices. The result is a diverse industry made up of around 70 producers of varying technical abilities. Prof Li Yimin and He Hao, from the State Key Laboratory for PM, Central South University, present a review of the development of MIM in China, from applications and materials to the broader challenges facing the industry.

China's Metal Injection Moulding (MIM) industry has made dramatic progress over the last decade. There is, however, a recognition within the Chinese MIM community that there are a number of challenges ahead to enable MIM technology to thrive as a mature manufacturing process.

It was for this reason that a major industry summit on MIM technology in China was recently held. The event, entitled "MIM Technology Industry Summit Forum: Industrialization Status and Development Trends" was organised by the Chemistry, Metallurgy and Materials Engineering Department of the Chinese Engineering Academy and took place in Changsha, Hunan Province, on October 12, 2013. The event was hosted by the Powder Metallurgy State Key Laboratory of Central South University (CSU), the National Engineering Research Center for Powder Metallurgy and the Powder Metallurgy Association of China's Materials Research Society. The summit also benefited from the support of a number of additional associations as well as Hunan Injection High Technology Co., Ltd.

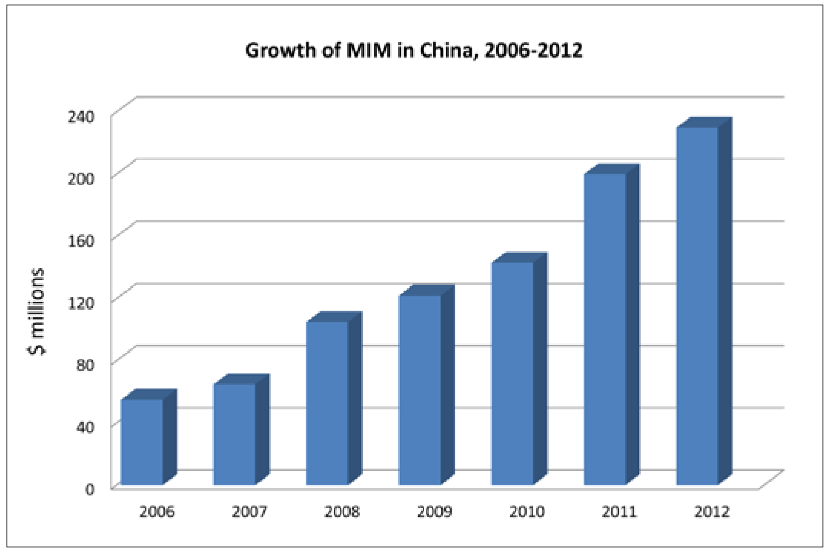


Fig. 1 Estimated MIM growth in China 2006-2012

Reflecting the strong interest in MIM in China, nearly 200 participants from industry and academia attended, as well as industry consultants and business leaders. Amongst these participants were delegates and speakers from renowned universities and representatives from leading parts producers and materials supplers such as Foxconn and BASF. Topics such as the current status of the industrialisation of MIM technology in China, development trends and technical issues were discussed in-depth. Much of the information presented at this seminar has been used in the preparation of this report.

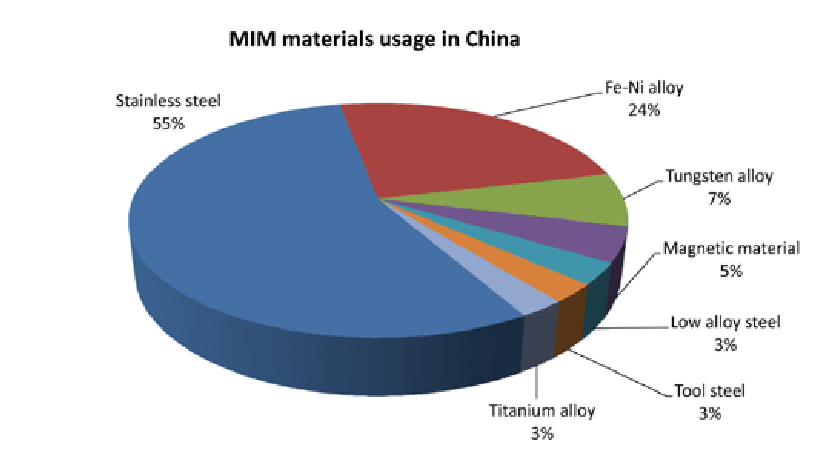


Fig. 2 MIM material usage in China

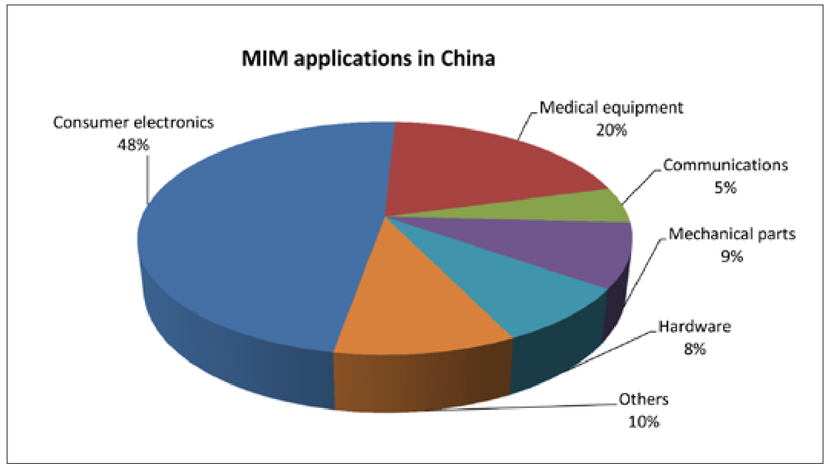


Fig. 3 Applications for MIM in China

Fig. 4 An example of a high volume MIM 3C electronic product: the Apple Lightning connector, shown with an iPhone 5

MIM and the Chinese economy

For the past thirty years, China has been one of the fastest-growing economies in the world with an average annual GDP growth rate of around 10%. In 2012, China's GDP amounted to RMB 51.9322 trillion. Products made in China are found all over the world and the country has become the world's second largest economy.

According to the statistics from the China Association of Automobile Manufacturers, the annual cumulative production of automobiles in China during 2012 reached 19.2718 million, with sales growing to 19.3064 million. Both figures beat previous records. The market share of domestic automobiles has exceeded that of imported automobiles since 2009.

As the statistics from the Ministry of Industry and Information Technology show, the output of mobile phones from China amounted to 1.13 billion in 2011. Gross export volume reached 880 million in 2011 and the total number of mobile phones exported is expected to be 1.3 billion during 2013.

It is shown from the monitoring data of China Competition Information office that the output of notebook PCs in China reached 253 million from January to December of 2012. 3C products are the biggest application market for MIM, so this fast growth brings huge market demand for the MIM industry.

As a result of such booming markets, large amounts of capital are being invested in MIM based on the advantages and potential of the technology. Newly-built MIM operations have therefore mushroomed in China. Nevertheless, the foundation of new MIM firms almost annually accompanies the bankruptcy of older firms. In other words, challenges often coexist with opportunities, which is the current status of MIM industry in China.

Prospects for MIM applications

In recent years the average annual growth rate of MIM in China has amounted to around 15%. Total sales of MIM parts by China manufacturers was estimated to be in the region of $230 million in 2012, as shown in Fig. 1.

With regards to materials, China's MIM industry is dominated by stainless steel. Tungsten alloys and hard alloys account for a considerable proportion while other high value-added materials, including titanium and aluminum alloys, as well as soft and hard magnetic materials, account for a relatively low proportion as shown in Fig. 2.

As previously mentioned, MIM in China is dominated by end-user applications such as 3C electronic products and automotive parts, as well as hardware and medical instruments. 3C products account for nearly half of end-user applications, as shown in Fig. 3.

Fig. 5 A selection of MIM automotive turbocharger parts

Fig. 6 General MIM automotive parts

Fig. 7 Various MIM hardware components

Fig. 8 Various MIM hardware components

3C products

In recent years there have been steady investments in large OEM factories in China for the manufacture of 3C products. This has created a huge demand for MIM components. Such mass produced small complex parts for 3C products are currently applied, for example, in the manufacture of the connectors, keypads and sealing components for tablet computers and mobile phones. Such orders can be extremely large with, as examples, the purchase of USB interface components for the Apple iPhone (Fig. 4) running up to 5 million parts per month and an iPhone keypad component amounting to more than 10 million parts per month.

MIM is the only feasible way to ensure a short lead time supply of such large quantities of highly complex precision components. However, to be able to deliver the short lead time supply of such large quantities of components demands significant up-front investments, high precision processing and high quality post-processing abilities that rely on a large number of manual workers. As an example the keypad components of the iPhone require a high Ra of more than 0.8 and tight tolerances of 0.01 mm. MIM companies which lack sufficient technical knowledge, and the ability to react quickly, will be under great pressure and may even lose their orders.

'Metal Injection Moulding is the only feasible way to ensure a short-term supply of large quantities of highly complex precision components'

The automotive market

Automotive parts are also characterised by very large orders, but in contrast to the 3C sector there is a great variety of components and longer term orders result in more stable demands (Figs 5-6). As an example, the purchase of a sliding bush amounts to 200,000 parts each month. Chinese automobile manufacturing technology is still in an early stage of development so that there is a certain discrepancy in the application of MIM technology when compared with countries with a more developed industry.

Additionally, automotive parts are manufactured in strict accordance with safety requirements. Improvement of MIM technology in China is therefore essential in order to meet these demands. Some high requirements must be met, such as high security, TS certification, strong technical performance and significant post-processing capability. The application of poorer MIM products would cause great risks in the automotive sector.

Fig. 9 MIM is used extensively in this multi-function tool

Fig. 10 Surgical device manufactured via MIM

Fig. 11 MIM surgical components

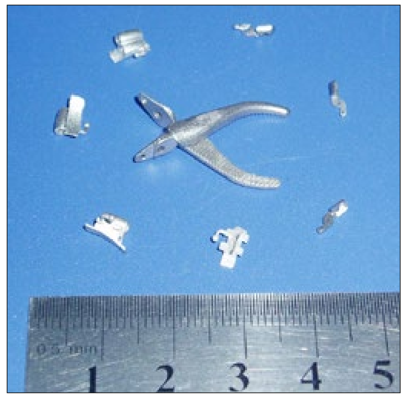


Fig. 12 Various MIM medical components

Hardware applications

The hardware sector consists of many applications, including locksets and electric hand tools, which have complex shapes suitable for MIM (Figs 7-9). The technology is applied to many parts such as swinging arms, connecting arms, the rotating shafts of lock bars, lock keys and electric tools. Although purchase quantities hardly match those of 3C electronics, because of the diversity of hardware parts this sector maintains a fixed share of the Chinese MIM market and makes steady progress. Hardware parts also meet with challenges because of their great variety, small quantity, complex structure and high cost. For instance, a lock set needs seven to eight MIM parts but the annual demand may only be for 100,000 sets.

The medical sector

The medical instruments sector is one of the most important application fields for Chinese MIM. Main products include binding clips, hand grips, scissors and forceps (Figs. 10-12). Because of the large population and the increasing quality of life expectations, the demand for MIM medical parts has maintained rapid growth since the beginning of the century. It is estimated that the annual total global market demand for disposal biopsy forceps, including peritoneoscopes, thoracoscopes, gastroscopes etc. is 300 million. However in China alone the number is 100 million.

The total annual demand for binding clips in China currently amounts to 20 million parts. Because of the complex shapes of many of these items, MIM technology saves nearly 70% when compared to conventional manufacturing routes. Medical instruments need, of course, to meet strict safety standards so quality has to be extremely high and suppliers must have the necessary technical skills to meet market demand.

'Medical instrument parts need to meet strict safety standards so quality has to be extremely high and suppliers must have the necessary technical skills to meet market demand'

The characteristics of MIM companies in China

With the rapid growth of MIM technology in China and the ever-increasing market demand for MIM products, the number of MIM companies has increased to around 70. MIM companies are divided into three types as shown in Table 1.

The first type of operation is the large scale MIM enterprise, rich in capital and able to offer a fast response to new application developments. There are three to five large powerful companies such as Foxconn and Zoltrix, all of which cover mould manufacturing, injection moulding and post-processing. In these companies, all the equipment is imported, including in some cases around one hundred injection machines and several continuous sintering furnaces. These enterprises generally use imported BASF feedstock. Thanks to the fast growth of 3C parts, they have led the way in China MIM in the last two years.

The second type of operation is the mid-sized enterprise, with lower capital and their own feedstock system. There are seven to eight mid-sized enterprises such as Hunan Injection High Technology (HIHT), Advanced Technology & Materials (AT&M) and Future Hi-Tech. In addition to strong size control, they have strong research and development ability and process various products with complex shapes. They typically have stronger post-sintering capabilities, including machining workshops and the ability to offer surface treatments via external suppliers. These enterprises can be seen as the "foundations" of the Chinese Metal Injection Moulding industry and are primarily involved in the hardware, medical and military markets.

The last type of MIM operation is the small enterprise, with limited production capacity and poor capital. There are about fifty such small MIM enterprises in China. Due to their limitations, such as limited technical ability and a lack of post-sintering treatments, they are only able to offer low accuracy products, often with simple shapes. Their customers are typically small domestic communications and hardware enterprises which are too small to place orders with the larger domestic MIM enterprises. As such, the outlook for these enterprises is gloomy.

Taking these wide differences into consideration, there is a belief that diverse and widely scattered MIM enterprises in China need to be more closely connected with each other. More attention has to be given to the integration of domestic MIM resources and engineering talent, even of capital investment and the financing of enterprises. In such a way improvement in product quality and production volume can be achieved, allowing greater competition with foreign MIM companies and allowing China's MIM industry to reach the level of a mature industry.

'The diverse and widely scattered MIM enterprises in China need to be more closely connected with each other and more attention has to be given to the integration of domestic MIM resources and engineering talent'

Powders and feedstock for MIM

At present, water and gas atomisation are the main methods for the manufacture of MIM grade powders. With regards to water atomised powder, AT&M Co., Ltd was one of the earliest companies to develop water atomisation process capability in China. In 2002 RMB 40.7 million was invested in the construction of an atomisation plant that today has an annual output capacity of 4000 tons for various high grade metal powders. Its powder products are mainly used for magnetic materials and MIM applications.

Some domestic private enterprises, including Shijiazhuang Lide Powder Company, Yahao Materials & Technology Company, Ningbo Feida Company and Qinhuangdao Shougang Changbai Machinery Compnay, have also adopted the water atomisation process to produce the non-spherical powders. Their products are mainly used for manufacturing the porous filtering materials, magnetic materials and diamond materials. In addition, a new water atomisation powder production line built by Guangzhou Research Institute of Nonferrous Metals is currently being commissioned prior to production.

As for gas atomised powder, the gas atomisation process in China was initially developed by the Powder Metallurgy Research Institute of Central South University. This technology is currently used by some domestic companies, such as Hunan Hengji Powder Technology Co., Ltd, for the industrial production of gas atomised metal powders. Its powder characteristics can meet the needs of MIM production.

Some of the new manufacturers do not sell solely to a specific industry such as MIM, but market their materials by powder size, from coarse to medium and fine. Moreover, the selling prices on the international market can be lower than the domestic state purchasing prices of the raw materials. It is therefore hard to reduce the production costs of fine powders. Compared with the imported powder, it is difficult to see a cost advantage.

Type of MIM company	Capital	Equipment	Technicians	Products	Feedstock	Post-processing
Large	Large	Imported	More than 30	3C	BASF	Yes
Medium	Medium	Typically imported	More than 20	Hardware, medical industry, firearms	BASF and in-house	No
Small	Small	Domestic	Less than 10	Low accuracy products	In-house	No

Table 1 An analysis of the types of MIM firms operating in China and feedstock types used

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Fig. 13 Gear prototypes with controlled interface morphology prepared by co-MIM

Fig. 14 Photographs of prepared ball gear

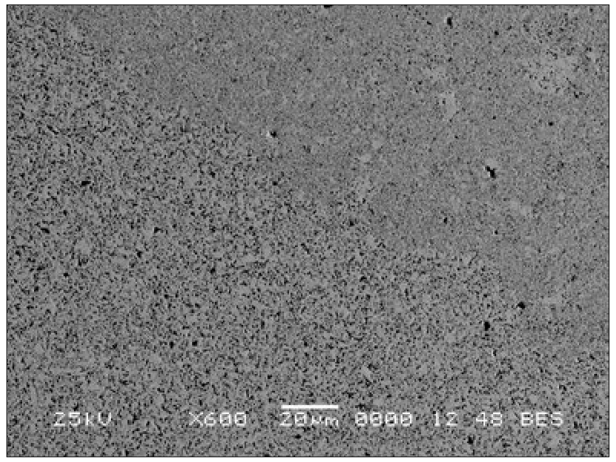

Fig. 15 The interface between fine and coarse powder

Carbonyl iron powders are produced by a number of domestic manufacturers including Jianyou Hebao Nanomaterial Co., Ltd, Shanxi Xinghua Chemistry Co., Ltd, Jiangsu Tianyi Ultra-fine Metal Powder Co., Ltd and Jiangxi Yue'an Ultra-fine Metal Co., Ltd etc. The last two private manufacturers have cultivated their own customers in MIM industry.

Feedstock production and usage

In terms of feedstock for MIM, the earlier entrants in China mostly adopt the wax based binder system and use in-house prepared feedstock. More recent entrants into the market typically use the premixed Catamold feedstock from BASF. Although Catamold has gradually predominated in the MIM industry, small-volume premixed feedstock is supplied by a number of domestic enterprises such as Beijing Weina Baode Technology Co., Ltd, Jinan Tongfa Technology Co., Ltd, Shenzhen Gredmann Company and Jiangxi Yue'an Ultra-fine Metal Co., Ltd. These small companies are characterised by lower volume feedstock production which can bring the risk of unpredictable feedstock performance. Their customers cannot afford the higher price of BASF feedstock and do not have their own feedstock production capacity.

New technology developments

Today continuous research and development drives the development of MIM technology forward at a fast rate. In China more and more attention has been paid to Metal Co-Injection Moulding (co-MIM), Micro Metal Injection Moulding (µ-MIM) and mould filling simulation.

Metal Co-Injection Moulding (co-MIM)

Co-MIM is a novel combination of conventional Metal Injection Moulding and polymer sandwich injection moulding, which offers the opportunity to combine two metallic materials with completely different properties in one component. It uses two different powder/binder mixtures which are injected into a mould sequentially, so that one mixture forms the surface layer of the component and the other forms the core.

There are some co-MIM parts under development in Central South University. Gear prototypes with controlled interface morphology have been prepared by co-MIM and the thickness of the surface can be as thin as 0.4 mm without breakthrough as shown in Fig. 13. The aim of the study is to provide functionally performing gears that require a combination of toughness and wear resistance (the skin is Fe2NiCr while the core is Fe2Ni).

A research group in CSU has also prepared a prototype ball gear. The ball gear is produced by co-MIM process using 0.3 µm tungsten carbide powder as the skin, which provide high hardness, and a 3 µm tungsten carbide powder as the core providing the required toughness. The prepared parts are shown in Fig. 14 and the interface of the fine and coarse powders showing a metallurgical bond without defects is shown in Fig. 15. The product is expected to have a superior mechanical properties and a long life.

In addition, Lianjian Chen and Yimin Li from Central South University have proposed a new bio-mimic implant structure, which has dense structure in the cortical bone area and porous outer and dense interior in the cancellous bone area, as shown in Figs.16-18. The structure is superior in transferring implant-bone interface stress to the surrounding bones. The porous outer layer has a controlled porosity in the range of 5–60 vol. % and pore size up to 400 µm. It facilitates the cell adhesion, in-growth and proliferation.

Micro Metal Injection Moulding (µ-MIM)

Micro Metal Injection Moulding is a promising process route to manufacture components with dimensions in the micrometer range, which fulfils the demands of intricate metallic and ceramic parts needed in micro-systems. The rapid development of Microsystems Technology (MST) creates a growing demand for intricate, three dimensional micro components or micro-structured components. Micro-

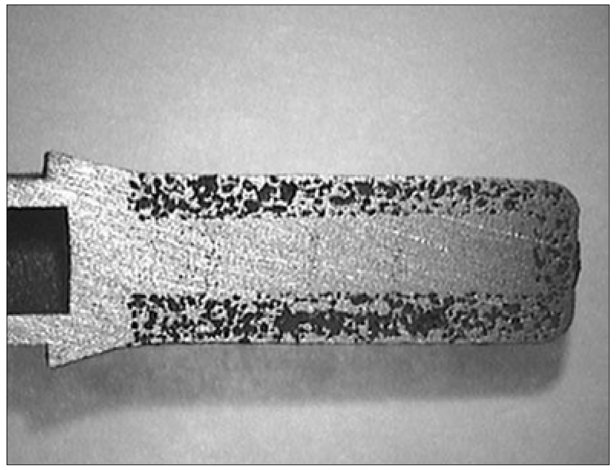

Fig. 16 The prepared bio-mimic titanium implant

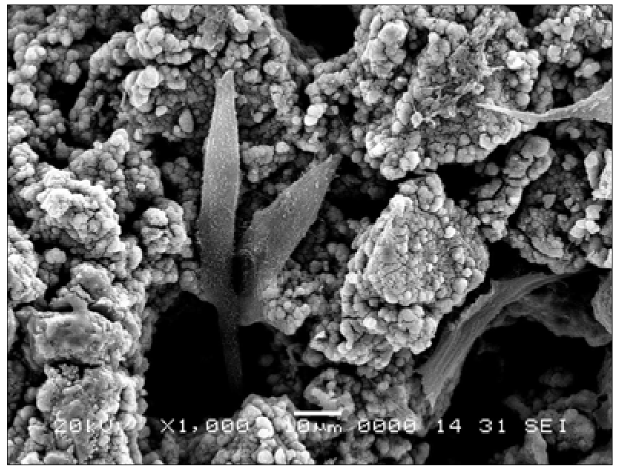

Fig. 18 MG63 cells grew well on the surface

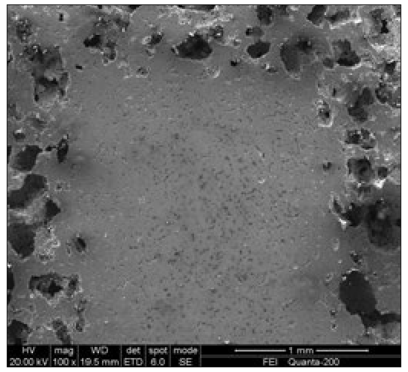

Fig. 17 The interface between porous outer and dense interior shows no cracks

Metal Injection Moulding (µ-MIM), a miniaturised variant of Metal Injection Moulding, has advantages in terms of shape complexity and mechanical properties. Stainless steel and ceramic parts with dimensions ranging from 200~700 µm were prepared, the dimension tolerance is ±3 µm, the roughness of green and ceramic micro-structured parts are 0.28~0.33 µm.

Mould filling simulation (Granular model)

Computer-aided design has been used in MIM for many years. It is mainly used for the prediction of the behaviour of the material during the moulding process and the optimisation of processing conditions. Researchers have tried to solve the equations within the continuum mechanics framework, for example the Finite-Element Method (FEM) or the Finite-Difference Method (FDM). Unfortunately, continuum models can only be applied to describe the macro-rheological behavior, and they are inadequate to describe micro-rheology. They are incapable of simulating the movement of powder and binder in the mould filling process and therefore cannot solve the problem of the separation of powder and binder, as well as the inconsistent distribution of powder and binder. This will cause distortion and dimension change in the later debinding and sintering process. Iwai and co-authors have been concerned with granular modelling. The granular model considers each granular particle distinctly and the powder characterisation and structures can be expressed explicitly. However, parameters in their model, such as tangential stiffness coefficient, normal stiffness coefficient are hard to measure and inappropriate for describing the properties of the feedstock.

In China, a group of researchers has developed a granular model from scratch, with the equations obtained including parameters concerning powder and binder characteristics and moulding parameters only, such as particle size, rheological behaviour of the binder, injection temperature and injection velocity. Thus it is directly applicable to theMIM process.

Summary

After more than twenty years of development MIM is gradually being accepted as a competitive material shaping process in China. The rapid growth of Chinese MIM reflects the huge market that Chinese and foreign manufacturing industries have created.

The strong development of the 3C electronics industry has created great opportunities for the fast growth of MIM enterprises and this market now accounts for about half of the total MIM sales in China. The need for investment in post-sintering operation capabilities, however, brings great challenges for small and medium-sized enterprises. Looking ahead, the steady development of MIM automotive parts will bring about explosive growth. At the current time, however, there is a general awareness of the risks of excess of production capacity caused by the fluctuating demand for ultra high volume 3C components, particularly for the smartphone sector.

It follows that the diversification of MIM markets in China means that the industry is about to move to a state of maturity. There are of course challenges that accompany the opportunities. Even though efforts to develop new materials and technologies for MIM are ongoing, the industry in China has a long way to go to before it is fully regarded as a mature industrial process.

Additionally, in order to meet the demands of a changeable market and the strict requirements for product quality, Chinese MIM companies have to improve their own management and technical abilities.

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Element 22 GmbH: Pushing the boundaries of titanium MIM in the medical and aerospace sectors

Element 22 GmbH is a leading manufacturer of titanium components by Metal Injection Moulding based in Kiel, northern Germany. The company has been instrumental in the development of ASTM standards for titanium MIM surgical implants and the company is the first producer to receive worldwide approval for these products. Dr Georg Schlieper visited the company on behalf of *PIM International* and reports on the current status of its technology and future expectations for titanium MIM.

Titanium has the atomic number 22 in the periodic table and Element 22 GmbH was therefore a natural choice for the name of a leading manufacturer of titanium components. Based in Kiel, a seaport on the Baltic Sea in northern Germany, the company is exclusively focused on the development and production of titanium components by Metal Injection Moulding (MIM). Its facilities are located on the grounds of the city's former central fish market which has been converted to a business park.

Matthias Scharvogel, Executive Director of Element 22 GmbH, is the sole shareholder of the company. Previously he had worked as a mechanical engineer for the Heraeus Group in Hanau, Germany, a company focusing on precious and special metals such as tantalum, niobium and titanium. He lived in the US for many years where he gained invaluable experience setting up a plant for advanced medical products.

Former business relations brought Scharvogel in contact with TiJet Medizintechnik GmbH and the manufacture of complex titanium parts by Metal Injection Moulding. From 2003 to 2011 TiJet had developed and produced numerous MIM titanium parts for the medical sector. However the company also encountered long and difficult periods solving technical problems and seeking product approval. Element 22 took over the entire operation of TiJet in the autumn of 2011 through an asset deal.

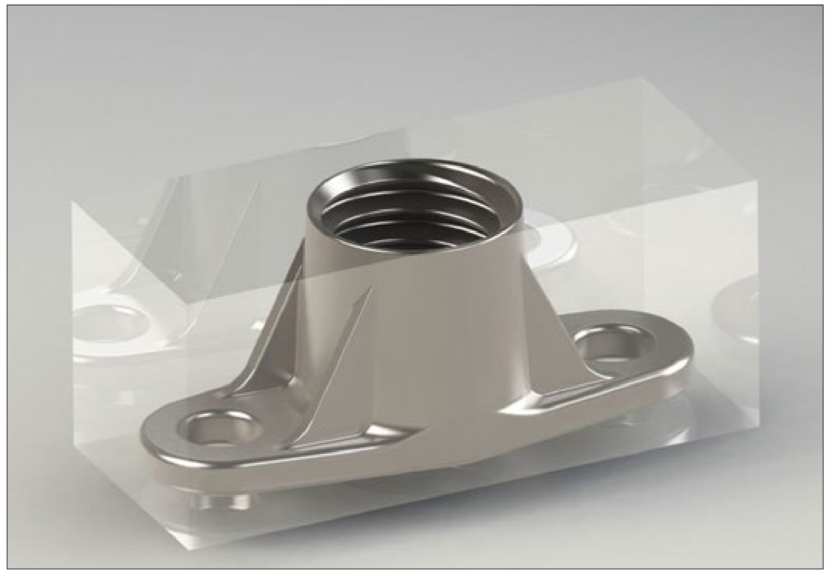

Fig. 1 Visualisation of raw material waste by machining a titanium component from bar stock (Courtesy Element 22 GmbH)

Chemical composition	ASTM F2885 (MIM Ti6Al4V)		ASTM F1472 (wrought Ti6Al4V)	
	min.	max.	min.	max.
Nitrogen	--	0.05	--	0.05
Carbon	--	0.08	--	0.08
Hydrogen	--	0.015	--	0.015
Iron	--	0.30	--	0.30
Oxygen	--	0.20	--	0.20
Aluminium	5.5	6.75	5.5	6.75
Vanadium	3.5	4.5	3.5	4.5
Yttrium	--	0.005	--	0.005
Titanium	--	balance	--	balance

Mechanical properties	ASTM F2885 (MIM Ti6Al4V)		ASTM F1472 (wrought Ti6Al4V)
	Type 1 densified	Type 2 as sintered	
Ultimate Tensile Strength (min.)	900 MPa	780 MPa	895 MPa
Yield Strength, 0.2% offset (min.)	830 MPa	680 MPa	825 MPa
Elongation to fracture	10%	10%	10%
Reduction of area	15%	15%	25%

Table 1 Specifications of ASTM F2885 for MIM Ti6Al4V and of F1472 for wrought Ti6Al4V (Courtesy Element 22 GmbH)

The importance of ASTM standards for titanium MIM

Scharvogel quickly realised that there was an urgent need to establish international standards for titanium MIM if the technology was to have any chance of securing a share of the medical market. He therefore took the decision to become a member of the ASTM Standards Committee F04, where he joined the subcommittee that was responsible for titanium MIM standards.

Two standards for titanium MIM surgical implants, F2885-11 for the most widely used titanium alloy Ti6Al4V and F2989-13 for pure titanium, were written and published with his active participation and the in-depth experience of his colleagues. A comparison of the material specifications for MIM Ti6Al4V and wrought Ti6Al4V is given in Table 1. The chemical compositions are identical, in particular the strict limits for nitrogen, carbon, oxygen and iron are the same for MIM as for wrought titanium. For the mechanical properties both ASTM specifications distinguish between the as-sintered and densified condition. Densified refers to the final elimination of residual porosity after sintering through Hot Isostatic Pressing (HIP). The as-sintered strength properties of MIM Ti6Al4V are 10-20% lower than those of the wrought material.

"It was of great importance for the approval of MIM titanium components for surgical implants by the US Food & Drug Administration (FDA) to have these standards. Our customers also appreciate that they can refer to international standards rather than just a company standard," stated Scharvogel. The standards, with their demanding requirements, can only be met with expert knowledge on how to process titanium and its alloys. These standards could only be issued because MIM technology can match the chemical composition of wrought titanium and the biocompatibility of MIM titanium is equal to wrought titanium. Element 22 GmbH is the first producer of MIM titanium products to have worldwide approval for surgical implants, including by the FDA.

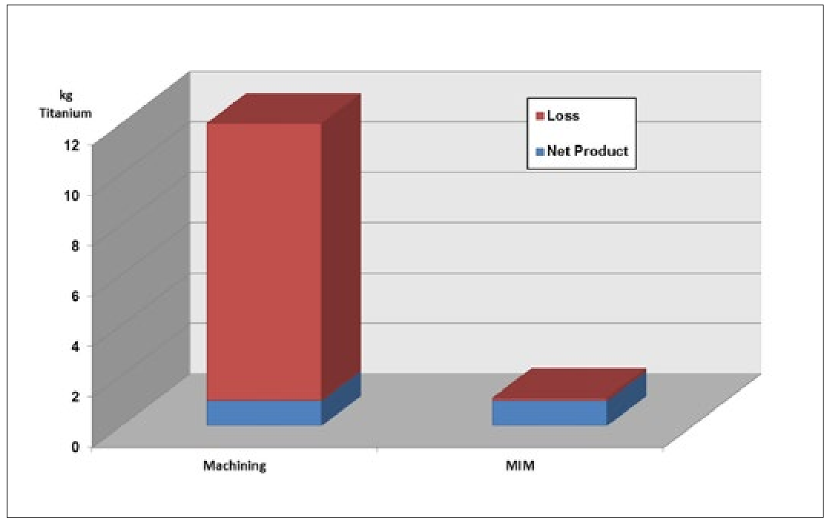

Fig. 2 Raw material utilisation by machining and MIM (Courtesy Element 22 GmbH)

Raw materials and energy efficiency of titanium MIM parts production

Much of the enthusiasm of Element 22 for the future of MIM titanium is due to the fact that the MIM process is extremely efficient in terms of raw materials utilisation, energy requirements and carbon dioxide emissions. In machining from bar stock enormous quantities of raw material are cut away, as shown in Fig. 1

According to Element 22 the total weight of raw material required for machined titanium parts is usually five to twenty times higher than the weight of the finished component. On average the ratio between raw material input and final product in the aviation industry, the so-called buy-to-fly ratio, is 12:1. The MIM process, in contrast, has a maximum loss of raw material of 10%, so the buy-to-fly ratio for MIM components is only 1.1:1 (Fig. 2).

The total energy requirement for producing a titanium component includes both the energy consumption for making the raw materials as well as the energy required for the manufacturing process. The production of titanium bar stock and titanium powder requires a similar amount of energy, namely 108 kWh/kg.

The average requirement of electrical energy for machining is 11 kWh/kg, however for the MIM process this is 32 kWh/kg. So for 1 kg of titanium parts manufactured by machining an energy input of 1304 kWh is required, whereas for MIM the energy consumption is only 150 kWh, corresponding to energy savings of 88% (Fig. 3).

These values can be converted into CO_2 emission with a simple factor. In the Western world 1 kWh electrical energy causes approximately 550 g of CO_2 emissions. Therefore on average the emission of greenhouse gas for producing 1 kg titanium parts by machining is 717 kg CO_2 and only 83 kg CO_2 for producing the same quantity of titanium components by MIM (Fig. 4).

This aspect of the technology is becoming more and more important under stricter legislation controlling greenhouse gas emissions. Companies that use titanium components can improve their greenhouse gas emissions by using more titanium MIM parts instead of machined parts.

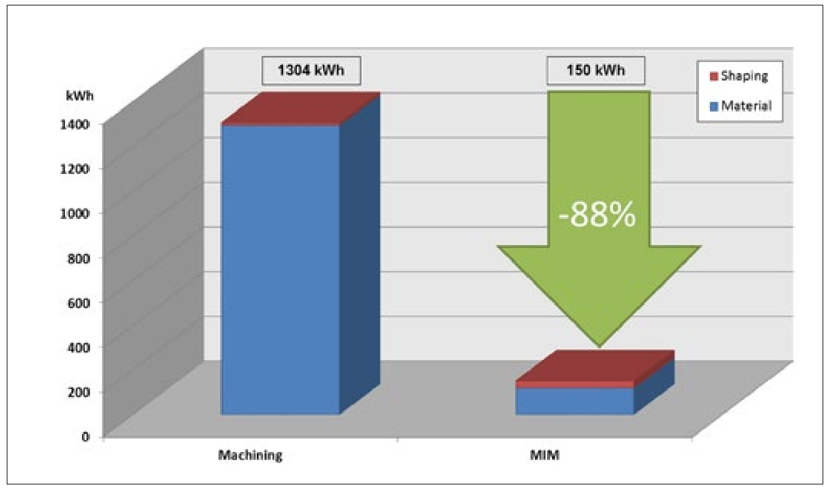

Fig. 3 Energy consumption by machining and MIM production (Courtesy Element 22 GmbH)

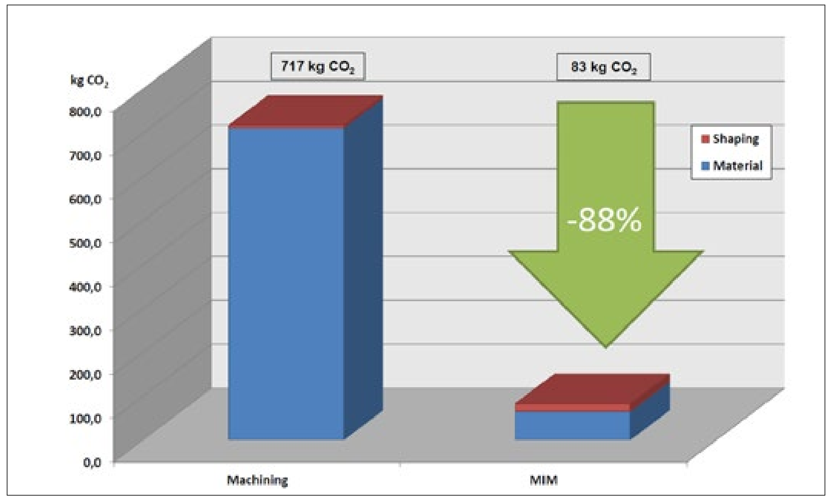

Fig. 4 Comparison of CO_2 emissions by machining and MIM (Courtesy Element 22 GmbH)

Comparison of material characteristics

A comparison of the material characteristics between titanium, stainless steel and a high strength aluminium alloy (Table 2) shows the advantages of titanium over the most widely used metals. The density of titanium is roughly half that of steel and double that of aluminium. The tensile strength of titanium is clearly higher than that of stainless steel and aluminium, and the difference is even more extreme for yield strength. Even at this high strength level there is still sufficient ductility, as indicated by the elongation to fracture. The corrosion resistance of titanium is unmatched by most other metals.

The strength-to-weight ratio indicates the load carrying capacity of components of equal size when made from different materials. This value is 65 for steel, 90 for high strength aluminium and 210 for Ti6Al4V alloy (Fig. 5). Even for pure titanium this value is higher than for steel. This means that titanium parts can be designed to be much thinner and lighter than steel or aluminium parts performing the same function, making the design of extremely light-weight structures possible that no other metal can match. Titanium is extremely corrosion resistant and the surface has a very pleasant touch when polished or shot peened.

Property	Titanium (Ti6Al4V)	Stainless Steel (304)	Aluminium (6061-T4)
Density, g/cm³	4.5	7.9	2.7
Tensile strength, MPa	900	650	200
Yield strength, MPa	830	290	110
Elongation to fracture, %	15	55	15
Corrosion resistance	excellent	good	fair

Table 2 Comparison of properties (Courtesy Element 22 GmbH)

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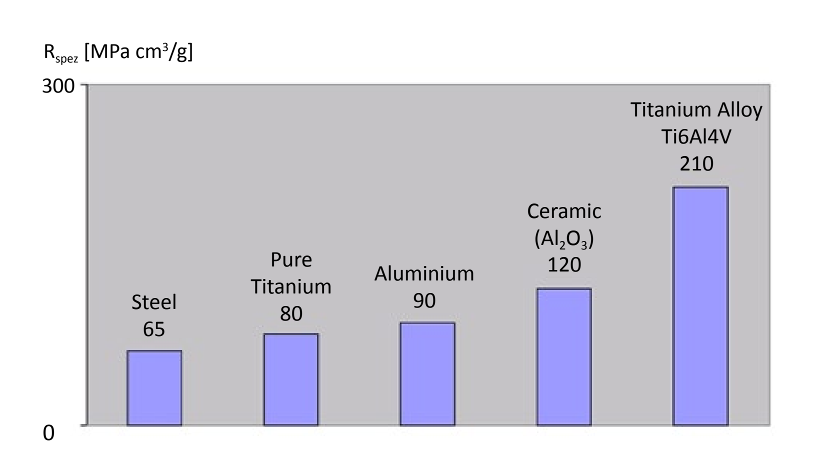

Fig. 5 Strength-to-weight ratio for various materials (Courtesy Element 22 GmbH)

Fig. 6 MIM titanium part with a polished surface

Fig. 7 Coloured titanium parts by anodic oxidation (Courtesy Element 22 GmbH)

MIM technology at Element 22

Over the years Element 22 has established close relations with the local technical universities and renowned research institutions in Northern Germany such as the Fraunhofer Institute IFAM in Bremen and the Helmholtz-Zentrum in Geesthacht. These universities are able to provide young engineers with a deep understanding of metallurgy and manufacturing technology, helping to meet the future demand of Element 22 for highly qualified engineers.

CAD and computer simulation of injection moulding is installed and plays an important role in the development of new components. A certified Quality Management System is an integral part of the company and employees are trained in this field. The certifications of the Quality Management System according to ISO 13485 and ISO 9001 were obtained in 2011 and 2012 respectively.

Wendelin Winkelmüller is responsible for research and development at Element 22. Winkelmüller stated, "It is to our great advantage that we compound our feedstock in-house. We can modify feedstock composition depending on the moulding requirements. Parts with very thin walls, such as housings for surgical implants, require a long flow length. In this instance the pressure could drop quickly as the feedstock tends to freeze. We have therefore developed a low viscosity feedstock with a long flow length that allows us to produce hermetically tight thin-walled housings."

'It is to our great advantage that we compound our feedstock in-house. We can modify feedstock composition depending on the moulding requirements.'

The MIM process at Element 22 consists of four steps: feedstock compounding, injection moulding, solvent debinding and combined thermal debinding and sintering. Metal powders with consistent and repeatable characteristics are essential for the successful production of MIM titanium parts. The powder morphology and the content of accompanying elements are strictly monitored. The powder is handled only under a protective atmosphere in order to minimise the pick-up of nitrogen and oxygen. After compounding the feedstock the binder provides sufficient protection to the powder particles so that the feedstock can be removed from the protective atmosphere.

Debinding is a two-step process; at first solvent debinding creates a "brown" part with open porosity. A subsequent thermal debinding is performed in the heating phase of the sintering process. The actual sintering is done in a high vacuum at temperatures around 1300°C. Sintered density is more than 96% of the theoretical density (4.54 g/cm³). Some parts are Hot Isostatically Pressed (HIPed) after sintering to remove the residual porosity. Typical production volumes are between 5,000 and two million parts per year.

Surface treatment is of prime importance for many products, both for aesthetic and technical reasons. Surface roughness after sintering is advantageous, for example, in many medical applications and shot peening or polishing is applied where required (Fig. 6). Applying different colours by anodisation is used to facilitate the distinction between different types of similar parts (Fig. 7).

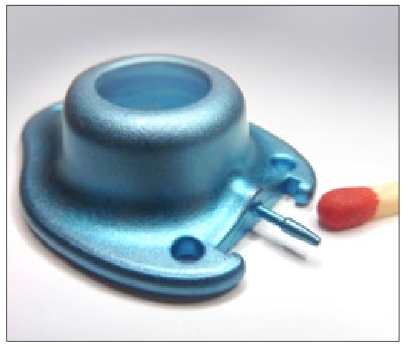

Fig. 8 Housing for an implantable port (Courtesy Element 22 GmbH)

Fig. 9 Thin-walled housings (Courtesy Element 22 GmbH)

The growing demand for MIM titanium products for medical applications

The need for small, thin-walled housings for surgical implants was one of the driving forces for the development of MIM titanium, overcoming the great design limitations when manufacturing titanium products by conventional methods. Medical device companies need components with excellent product quality and reliability that can only be created with validated technologies. Failures cannot be tolerated because they may be harmful for patients' health or could even threaten their lives. Cost pressures in the medical sector have also become stronger in recent years, ensuring that interest in titanium MIM products is increasing rapidly.

For Element 22 the medical industry is currently the most important market for MIM titanium parts and typical examples are housings for implantable devices. Fig. 8 shows a small port for a medication infusion device with a through hole of 0.3 mm diameter. The surface is colour coded in order to distinguish between different types of this port.

Thin-walled housings for surgical implants, as shown in Fig. 9, are a speciality of Element 22. A wall thickness down to 0.25 mm can be achieved. The housings are gas tight as proven by the helium leakage test. Optional Hot Isostatic Pressing is offered to eliminate the residual porosity. Titanium parts with such extremely thin, hermetically tight walls are extremely difficult to manufacture by means other than with MIM technology. Element 22 has acquired the know-how to produce such parts in large quantities.

Fig. 10 shows on the left an implantable screw with self-cutting threads at both ends for the repair of dens axis fractures. A hexagonal through-hole along the longitudinal axis enables fixing and unscrewing with a 3 mm Allen key. The part weighing approximately 1g is moulded without a draft angle. The dental implants shown on the right are directly screwed into the jaw bone. These parts are manufactured without any secondary operations and show the as-sintered surface, a feature that is advantageous for the quick integration with the bone.

Another example of the types of structures that can be achieved with MIM is the diffuser nozzle with an

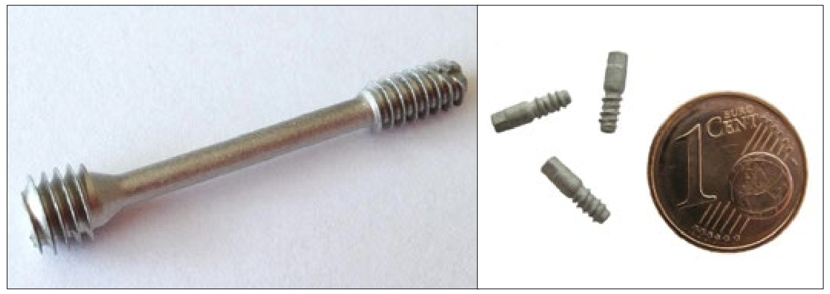

Fig. 10 Dens screw with longitudinal hexagonal through-hole approximately 80 mm long (left) and dental implants (right) (Courtesy Element 22 GmbH)

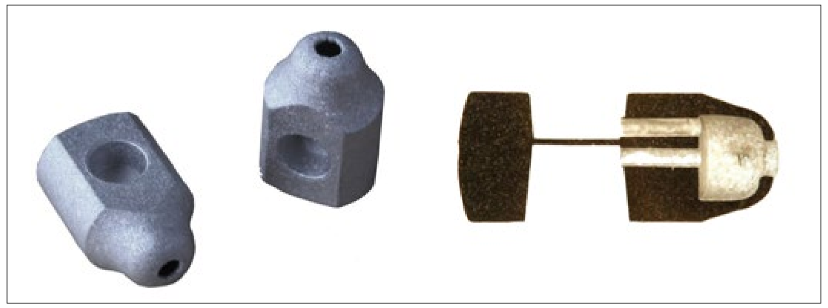

Fig. 11 Diffuser nozzle with an undercut (left) and cross-sections (right) (Courtesy Element 22 GmbH)

Fig. 12 Bone reinforcement plate (Courtesy Element 22 GmbH)

'Many new parts are ready for volume production, investments in further production equipment have been decided and continued growth is expected in the years to come'

undercut shown in Fig. 11. Element 22 manufactures this part for Bauer und Häselbarth-Chirurg GmbH. The finished part is on the left and cross-sections of the part is the right. The part enables the creation of a spray mist.

The bone reinforcement plate shown in Fig. 12 weighs only 10 g and is manufactured net shape with all features. The surface shown is as-sintered.

Aerospace and other markets

The aerospace industry is regarded as an even bigger market than the medical sector. The first titanium MIM parts are already being used in commercial aircraft in production quantities. Bolts, rivets, fasteners and other components are required in the hundreds of thousands for commercial aircraft and MIM has a good chance to further participate in this growing market.

The increasing use of Carbon Fibre Composites (CFC) in aircraft manufacturing has led to a strong increase in the demand for titanium parts, since aluminium, which has been used predominantly in the past, is incompatible with CFC due to corrosion. The proportion of titanium in modern aircraft like Airbus A350 and Boeing Dreamliner 787 is approximately 15 % by weight. Today, most of these components are produced by machining, including an enormous loss of raw material, since the buy-to-fly ratio is 12:1. MIM titanium with its nearly 100% raw material utilisation can contribute a lot to reduce this ratio. Alternative forming technologies and machining of titanium are extremely challenging and expensive when compared to MIM.

The third business sector, still in an embryonic stage, is high end consumer products. The superior material properties, design options and the visual appearance of titanium MIM are extremely attractive. Leading brands strive to protect their products by adding features that cannot be copied and make them easily discernible from low-cost copies. Furthermore, titanium is biocompatible; it does not irritate the skin.

In the jewellery industry the utilisation of materials other than noble metals has become more and more common. Ceramics, carbon fibre materials and also titanium are no longer unknown. Titanium is an attractive material and the design options of MIM technology speak for themselves. Combinations of titanium with ceramics are under development at Element 22.

Part development and marketing strategies

Although Element 22 has not yet exhibited at trade shows or advertised, there are a growing number of inquiries. However, the design of the requested components is often not well suited to MIM and a thorough design review is required. "Designers tend to think about the function of a part and not about the manufacturing process. It is our job to communicate the MIM design principles," says Matthias Scharvogel, and Wendelin Winkelmüller adds,"This is what we like to do."

Raw material costs are currently a limiting factor for bigger components since the cost of the titanium powder is roughly twice the cost of wrought titanium. The commonly used powder is spherical gas atomised with a particle size less than 45 μm. Future developments of a new process for titanium powder may lead to a substantial reduction of raw material costs however.

Much effort is invested in mould design and the objective is always to develop a part design that can be finished without any secondary machining operation as a so called net shape part. Close cooperation with competent tool manufacturers is important. Tools with up to six cavities are currently used. Element 22's low viscosity feedstock allows for designing extremely small gates that need no subsequent operation.

MicroMIM is regarded as an important future trend, particularly in medical technology where a tendency towards miniaturising components is obvious. Element 22 is developing several miniature parts for this market.

The majority of the customer base of Element 22 is in European countries, while the US is the second most important market. Element 22 is committed to further develop the North American market and Scharvogel's many contacts in the United States are of great help in this task. "After many years of process development and five years of continuous supplies to the medical industry, MIM titanium has become an established alternative to traditional manufacturing methods. Now the time has come for the next fundamental step forward towards high volume supplies to further markets. Many new parts are ready for volume production, investments in further production equipment have been decided and continued growth is expected in the years to come," concluded Scharvogel.

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PIM at Euro PM2013: Innovations in materials and processing highlighted in Gothenburg

Euro PM2013, Gothenburg, Sweden, once again served as an international platform for PIM researchers and industry suppliers to present the results of their latest research and development activities. As Dr Georg Schlieper reports for *PIM International*, this year's event included a number of interesting new materials developments as well as innovations in PIM processing technology. The event, which took place from September 15-18, was organised by the European Powder Metallurgy Association and attracted more than 700 participants.

Although Powder Injection Moulding (PIM) is today well established, there are still many researchers working to apply this technology to less common materials. This was reflected at Euro PM2013 in two technical sessions devoted to innovations in PIM materials. The first of these sessions addressed permanent magnets, tungsten-copper, a niobium-silicon composite and a high manganese steel.

Powder Injection Moulding Materials 1

Anisotropic NdFeB hard magnets by MIM

Thomas Hartwig, Fraunhofer Institute IFAM, Bremen, Germany, presented the results of research into the MIM production of neodymium-iron-boron (NdFeB) permanent magnets that had been carried out in cooperation with the Federal University of Santa Catarina, Florianopolis, Brazil.

Rare earth permanent magnets have the highest energy product known and are therefore used in high performance electric motors and demand is rapidly increasing. Although the required shapes are usually relatively simple, being rings, discs or cuboids, PIM technology offers better homogeneity when compared to conventional die pressing and this, according to Hartwig, can reduce machining cost and scrap, resulting in improved raw material utilisation of these expensive elements.

The main problem for PIM processing is the reactivity of the elements. Any contact with air, moisture, organic binder, sintering atmosphere or supporting material can lead to undesired chemical reactions with the ultra fine powder. This is why particular emphasis was placed on controlling the carbon and oxygen content of the sintered material.

The processing route for NdFeB magnets developed by IFAM and the University of Florianopolis starts with

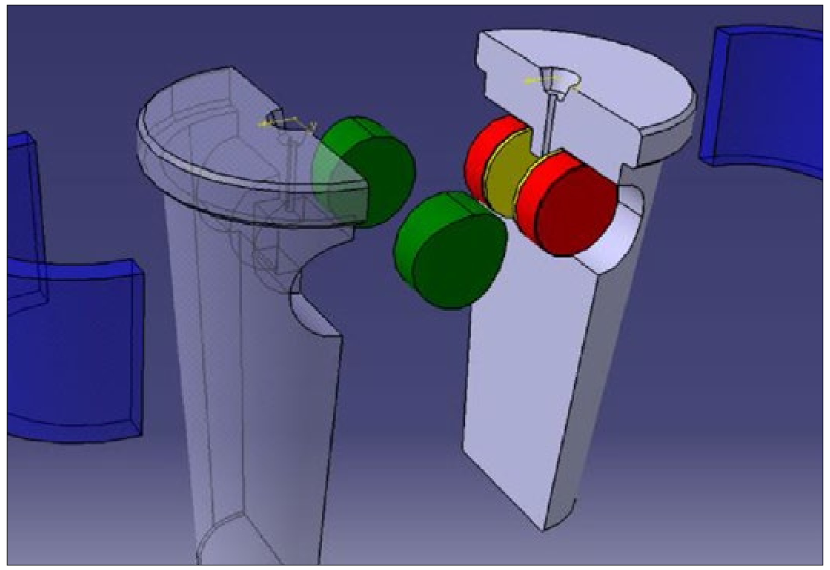

Fig. 1 Injection moulding tool for NdFeB magnets [1] (Courtesy EPMA)

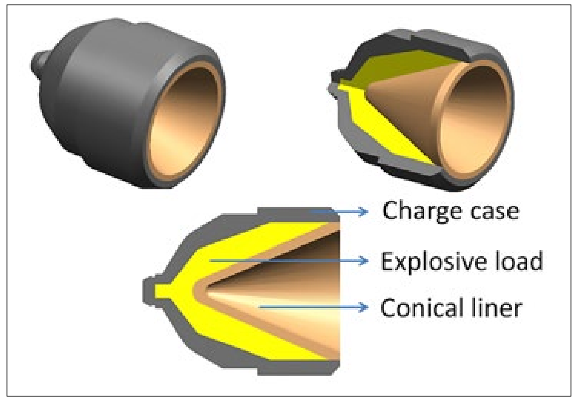

Fig. 2 Design of shaped charge [2] (Courtesy EPMA)

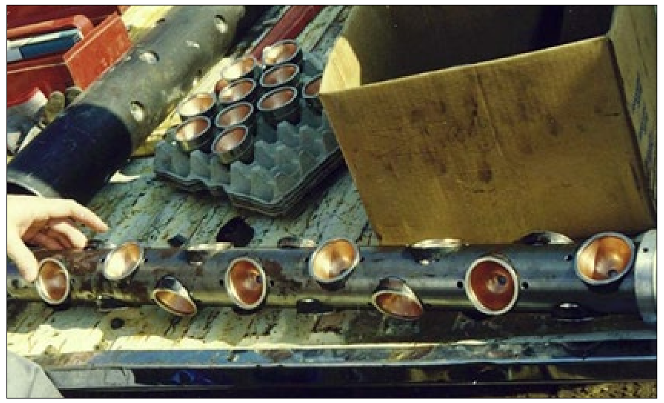

Fig. 3 Shaped charges assembled in a perforating gun [2] (Courtesy EPMA)

a powder composition in weight-percent 66.9% Fe, 25.1% Nd, 7% Dy, and 1% B with a particle size D50 of 5 µm. The powder was blended with a binder, the composition of which was not disclosed, at a powder loading of roughly 60 vol% and injection moulded in a magnetic field. The injection moulding tool is shown in Fig. 1.

'The mould cavity is placed between permanent magnets which create the required alignment of the magnetic particles'

The mould cavity is placed between permanent magnets (red) which create the required alignment of the magnetic particles.

The lowest carbon levels were reached after debinding with a heating rate of 0.1 K/min in hydrogen followed by sintering. Anisotropy levels similar to industrial magnets were achieved and a non-uniform shrinkage was observed depending on the orientation of the magnetic powder particles. The author stated that research will be continued on this subject.

Development of tungsten-copper shaped charge liners by MIM of ultrafine composite powder

An innovative product made by PIM technology was presented by Jiupeng Song, Xiamen Honglu Tungsten Molybdenum Industry Co. Ltd., China. The charge liners discussed have a conical shape and are part of an explosive charge system used to perforate the end zone of deep drills in the oil and gas industry (Fig. 2).

The charges are assembled in a perforating gun (Fig. 3) which is lowered into the well and then detonated. Each of the charge liners is deformed by the explosive energy into a jet of hot material with a high penetrating power that breaks up the surrounding rock and allows the oil or gas to enter into the well.

The material composition W-25% Cu was chosen due to its high density and ductility. An ultrafine powder with a D50 below 5 µm was mixed with a binder for solvent debinding at a powder loading of 50 vol%. Torque measurements on the kneader revealed that this was the optimum powder loading. After debinding and sintering the material achieved a density of 14.75 g/cm³ which is 98.8% of full density.

Although the MIM material of the charge liners was well sintered, the penetration was less than expected because the intensity of the explosion did not match with the MIM material. Further research will be directed at reducing the wall thickness of the charge liners, stated Song.

Nb-Si intermetallic composites for high-temperature applications produced by MIM

Progress in PIM processing of a Nb-Si intermetallic composite material for high temperature applications was reported by Marco Mulser, Fraunhofer Institute IFAM, Bremen, Germany. The material is composed of the intermetallic phase niobium silicide Nb5Si3 and a ductile niobium-rich matrix. The material has a density of approximately 7 g/cm³ which is significantly lower than nickel base alloys (9 g/cm³) and, according to IFAM, excellent mechanical properties at elevated temperatures so that it could replace nickel base alloys in turbine applications.

The most successful route started with gas atomised powder with a particle size of D90 = 32 µm. The powder was worked into a wax-polymer based binder at a powder loading of 70 vol%. Discs of D30 x 4 mm were injection moulded and subjected to a solvent debinding treatment with hexane. Subsequent thermal debinding and sintering was performed under argon gas on yttria coated plates and with titanium sponge as a getter material. The heating rate up to 600°C was 3 K/min, then, after a dwell time of 60 minutes, the heating rate was increased 5 K/min up to the sintering temperature of 1500°C which was held for 3 hours. The samples were cooled at 15 K/min.

The microstructure of the material exhibited less than 3% residual porosity, a large content of metal silicides (M5Si3) and hafnium oxide. The matrix was a Nb-Ti alloy (Fig. 5). The grain size was much finer and metal silicides were more homogeneously distributed than with other processes.

Future research will look to determining the effect of hafnium oxide in the material, optimise the sintering cycle and applying a post-sintering HIP treatment. It will further determine mechanical properties at room temperature and elevated temperatures, look to improve the oxidation resistance by coatings and finally manufacture a turbine component as a demonstrator.

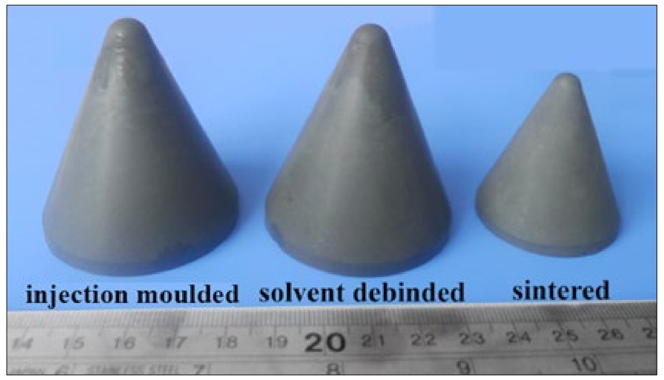

Fig. 4 Charge liners made from W-25Cu by PIM [2] (Courtesy EPMA)

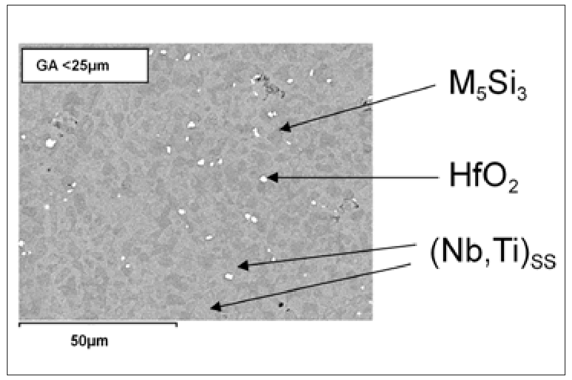

Fig. 5 Microstructure of Nb-Si material [3] (Courtesy EPMA)

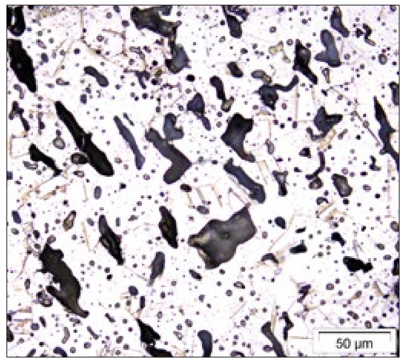

Fig. 6 Microstructure of MIM Hadfield steel exhibiting secondary pores [4] (Courtesy EPMA)

Sinterability and microstructure formation of a Hadfield steel produced by MIM

The last presentation of this session was given by Renan Schroeder of Embraco, Brazil, which claims to be the largest producer of compressors for refrigerators and other appliances in the world. The work had been performed in cooperation with the Materials Laboratory (LabMat) of the Federal University of Santa Catarina, Florianopolis, Brazil. Embraco has an interest in materials for compressor parts with low friction and high wear resistance. Hadfield steel with a composition Fe-12% Mn-1% Si-1% C was selected as a candidate for MIM production due to its favourable combination of properties.

The results of Hadfield steel produced from prealloyed powder had already been reported at Euro PM2012. This time, an attempt was made to produce the steel via the master alloy route, i.e. from carbonyl iron, ferro-manganese, ferro-silicon and graphite. The effect of each master alloy powder on the densification during sintering under argon + 5% H_2 gas was studied separately in dilatometer experiments.

The results confirmed that this alloy containing Mn and Si in high concentrations will heavily oxidise during sintering unless the oxygen potential is kept at extremely low levels. The researchers achieved that by adding titanium chips into the furnace.

The particle size of ferro-manganese and ferro-silicon powders is also significant for the densification of the alloy. With an average particle size of approximately 45 µm, which was used in the study, large secondary pores were created (Fig. 6) and the sintered density was not satisfactory. Further research is required to improve the results stated Schroeder.

Powder Injection Moulding Materials 2

Titanium is very difficult to process by MIM due to its high sensitivity for C, N and O impurities which lead to a severe reduction of the ductility. Two researchers trying to overcome these difficulties and meet the requirements of ASTM standards encountered the expected difficulties, whilst other research on MIM materials was related to the INVAR 36 alloy and porous 316L stainless steel.

High cycle fatigue of titanium fabricated by Metal Injection Moulding

Katharina Horke of the Institute for Advanced Materials and Processing at the University Erlangen-Nuremberg, Germany, presented results of high cycle fatigue testing of MIM titanium

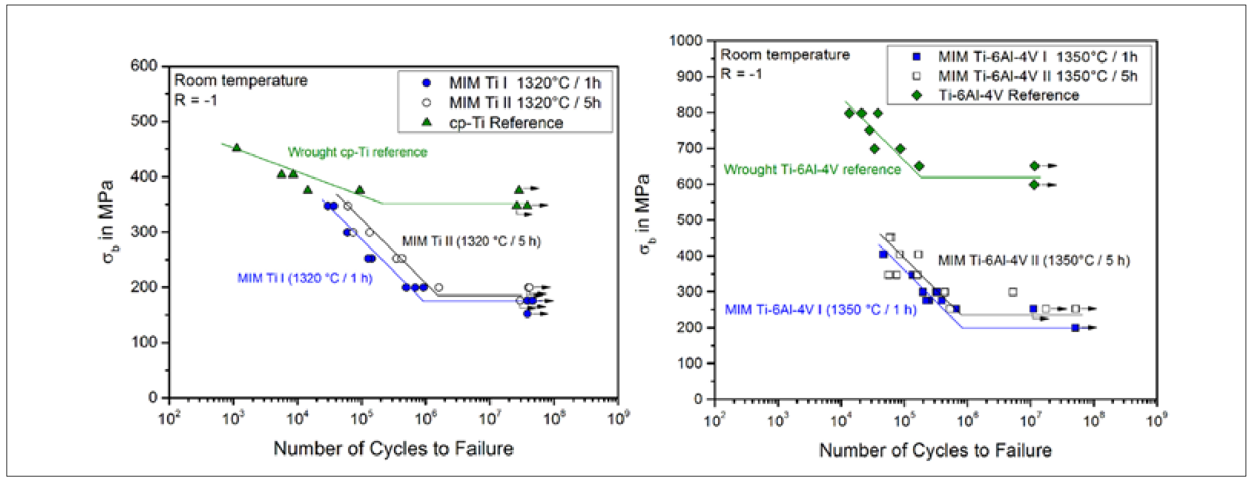

Fig. 6 S-N curves for Ti (left) and Ti6Al4V (right) [5] (Courtesy EPMA)

Specimen composition	Initial powder value		Sintered specimen		
	Oxygen [μg/g]	Nitrogen [μg/g]	Oxygen [μg/g]	Nitrogen [μg/g]	Oxygen pick up [μg/g]
Ti-Al6-V4	1500	100	2850	530	1350
Ti-Al6-V4 + 0.5 wt.-% Ce	1300	220	2145	645	845
Ti-Al6-V4 + 0.5 wt.-% CeSi2	1300	220	1750	715	450

Table 1: Oxygen and nitrogen contents of initial powder and sintered specimens [6] (Courtesy EPMA)

Specimen composition	YS [MPa]	UTS [MPa]	εf [%]
Ti-Al6-V4	781	892	11
Ti-Al6-V4 + 0.5 wt.-% Ce	666	779	7.6
Ti-Al6-V4 + 0.5 wt.-% CeSi2	685	789	7.7

Table 2 Yield strength (YS), tensile strength (UTS) and elongation to fracture (εf) [6] (Courtesy EPMA)

as well as Ti6Al4V according to ASTM B348 grade 3 and 5, and compared them to wrought titanium. Starting from feedstock with a water-soluble binder, rods of 8.75 mm diameter and 90 mm length were injection moulded. Tensile and rotating bending fatigue test samples were machined from these rods after sintering at 1320°C (Ti) and 1350°C (Ti6Al4V) in high vacuum.

While the tensile and yield strength of MIM titanium were in accordance with the ASTM standard and MIM Ti6Al4V almost reached the standard values, the elongation to fracture was relatively low and the fatigue strength less than half of the wrought samples (Fig. 6). Negative influence was attributed to larger grain size, residual porosity and interstitial elements C, N and O. It was reported that a prolonged sintering time of five hours instead of one hour did not lead to fundamental improvements.

Horke made it clear that her work will be continued and that there is ample room for improvement of the fatigue strength of MIM titanium. Strategies include optimised sintering parameters, use of different titanium powders and HIPing.

Addition of rare earth elements to MIM processed Ti-6Al-4V

The effects of cerium and cerium silicide additions to MIM Ti6Al4V were studied by Wolfgang Limberg, Helmholtz-Zentrum Geesthacht, Germany. Cerium oxide is more stable than titanium oxide and therefore cerium is a candidate to improve the ductility and strength of titanium alloys. All samples were injection moulded, debound and sintered under the same conditions. The sintering was done at 1350°C / 2h in high vacuum. Table 1 shows that the oxygen level after sintering was indeed reduced by cerium and even more by cerium silicide. The nitrogen content, however, was increased. The mechanical properties (Table 2) do not reflect the reduction of impurities. The strength and ductility were both reduced.

According to the author's interpretation of these results the main reason for the lower strength was that the residual porosity of the material with Ce and CeSi2 was about three times higher than that of pure Ti6Al4V.

Effect of debinding and sintering atmospheres of low expansion INVAR alloy for μ-PIM

A MIM process for the INVAR 36 (Fe-36% Ni) alloy, which is characterised by an exceptionally low coefficient of thermal expansion (CTE), was presented by Javier Hidalgo from University Carlos III, Madrid, Spain.

The author expected this alloy to be of particular interest for microMIM applications where excellent dimensional stability is required at varying temperatures. Gas atomised prealloyed powder with a maximum particle size of D90=5.9 μm was compounded with a binder of cellulose acetate butyrate (CAB) and polyethylene glycol (PEG). The feedstock containing 65 vol-% metal powder was injection moulded into flat micro tensile bars and flat rectangular samples (Fig. 7).

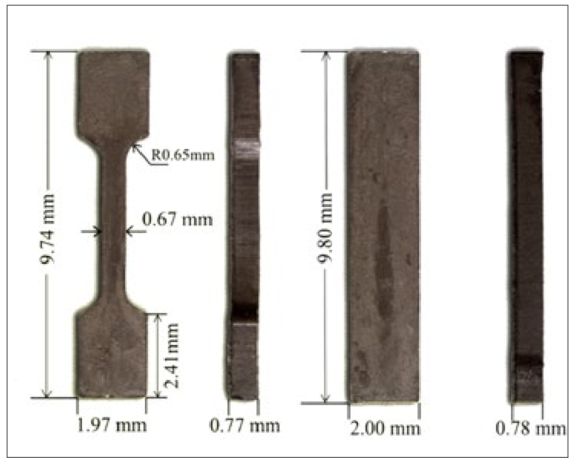

Fig. 7 Sample geometries [7] (Courtesy EPMA)

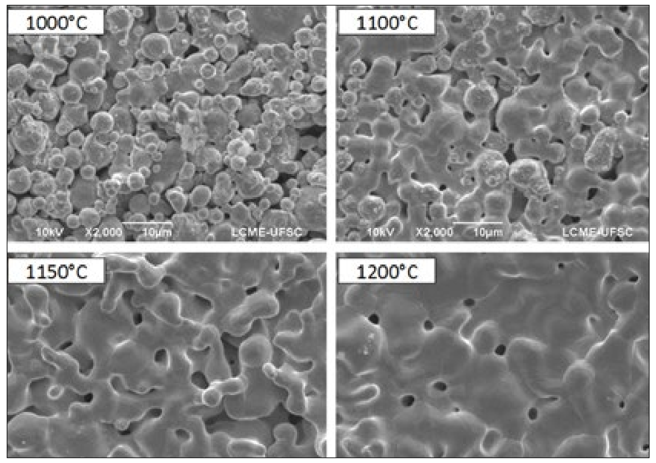

Fig. 8 Structure of porous MIM stainless steel depending on sintering temperature [8] (Courtesy EPMA)

The processing conditions included solvent debinding in water at 60°C, thermal debinding up to 400°C with a heating rate of 2°C/min in air and vacuum and finally sintering at 1100°C in vacuum and hydrogen. Unsurprisingly, debinding in air leads to oxidation that has to be reversed during sintering. This can best be done in hydrogen, however hydrogen has a negative effect on the ductility and the CTE value. In vacuum sintering it is difficult to completely eliminate the carbon and reduce oxides. Therefore the author did not give a clear recommendation for the processing parameters of this alloy.

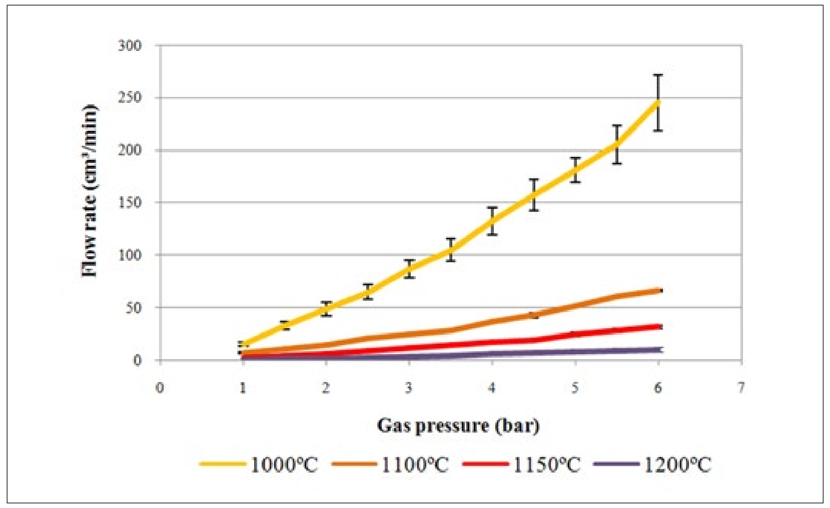

Fig. 9 Gas flow through porous MIM stainless steel elements [8] (Courtesy EPMA)

Tailoring the porous microstructure of MIM flow restrictors

Kaline Furlan, Materials Laboratory (LabMat), University of Santa Catarina, Florianopolis, Brazil, reported on the development of porous MIM elements for the application of gas flow restrictors.

Gas atomised 316L stainless steel powder with a maximum particle size of D90=22 μm was compounded with 6.5% thermoplastic binder. From this feedstock small cylinders of 2.5 mm diameter and 3.5 mm height were injection moulded. Solvent debinding was performed in hexane at 60°C/5 h and subsequently accelerated thermal debinding was carried out in a glow discharge hydrogen plasma up to a maximum temperature of 650°C with a presinter dwell time of one hour. Sintering was done in a vacuum furnace at temperatures of 1000°C, 1100°C, 1150°C and 1200°C.

The SEM images of the surfaces of these porous elements show impressively how the pore structure changes with increasing sintering temperature (Fig. 8). At 1000°C the original powder particles are still visible, at 1100°C a sintered material with open porosity has formed which is further densified at 1150°C and 1200°C.

The gas flow through porous stainless steel elements is shown in Fig. 9. The highest flow rates are achieved at a sintering temperature of 1000°C. With increasing sintering temperature the density and the proportion of closed and blind pores increases which has a negative effect on the gas flow.

PIM Processing

Some interesting developments in PIM processing were presented in Session 13. These related to improved dimensional accuracy in microPIM, micro powder in-mould labelling, a study of an eco-friendly water soluble binder system, modelling of the viscosity of binder mixtures and finally a joining technique for green PIM compacts.

High-grade micro components produced by variants of Powder Injection Moulding

When it comes to microPIM, accuracy is the key issue since even small dimensional errors are relatively large in relation to the component's small size. Volker Piotter, Karlsruhe Institute of Technology, Karlsruhe, Germany, presented a systematic experimental approach to improving the dimensional accuracy by optimising the gate position for injection moulding. Both metallic (17-4PH) and ceramic (ZrO_2) feedstocks were injection moulded in an experimental tooling with a cylindrical shape, which allowed variation of the gate position with movable pistons at both ends (Fig. 10).

The cylinder was 2.015 mm in diameter and had a length of 20 mm. The standard deviation of the measurements on the diameter of the cylinder was evaluated as an indication of the achievable dimensional accuracy. The results showed that the accuracy

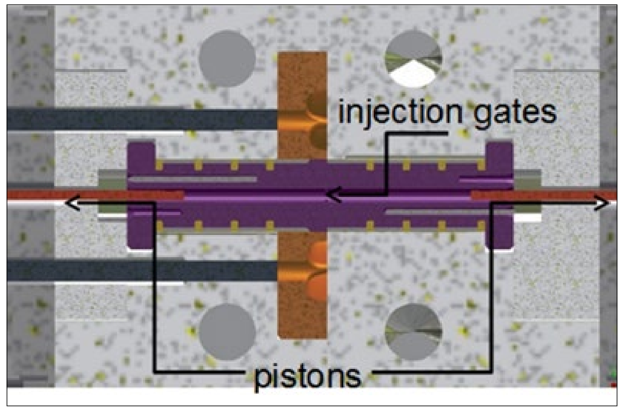

Fig. 10 Experimental mould for cylindrical samples with movable pistons [9] (Courtesy EPMA)

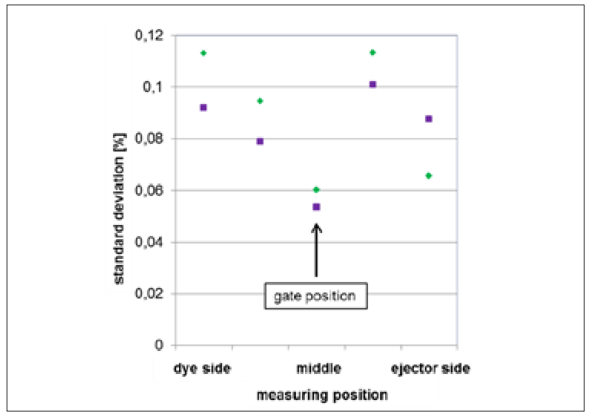

Fig. 11 Dimensional accuracy of green (rhombus) and sintered (square) samples [9] (Courtesy EPMA)

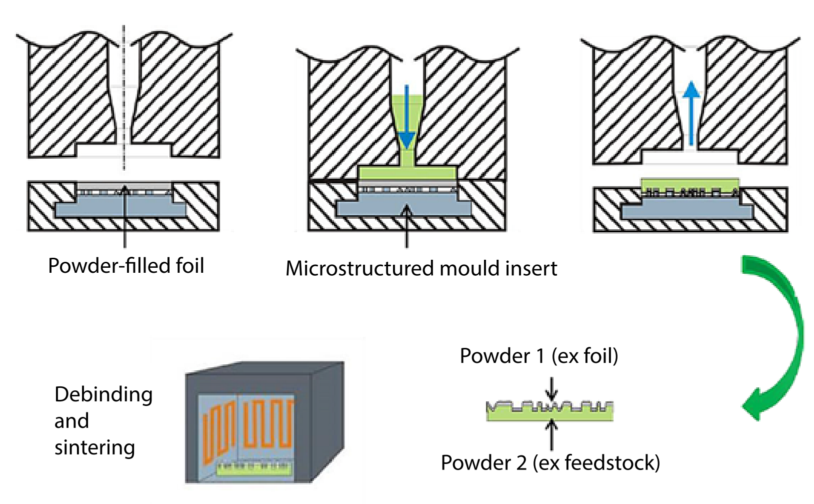

Fig. 12 Flow chart of micro powder in-mould labelling [9] (Courtesy EPMA)

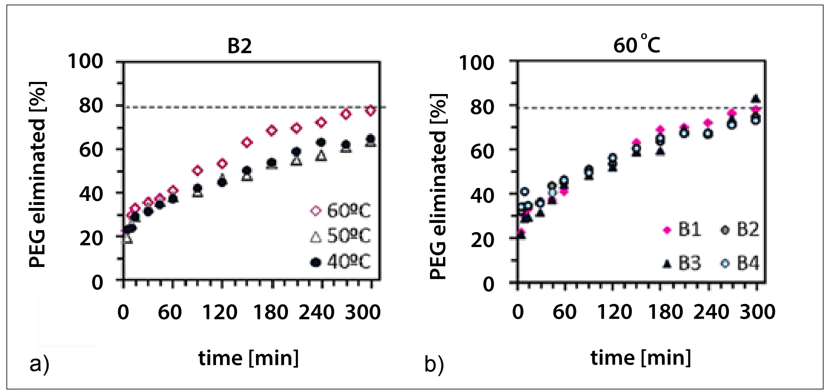

Fig. 13 Solvent debinding removed 80% of PEG in 5 hours at 60°C [10] (Courtesy EPMA)

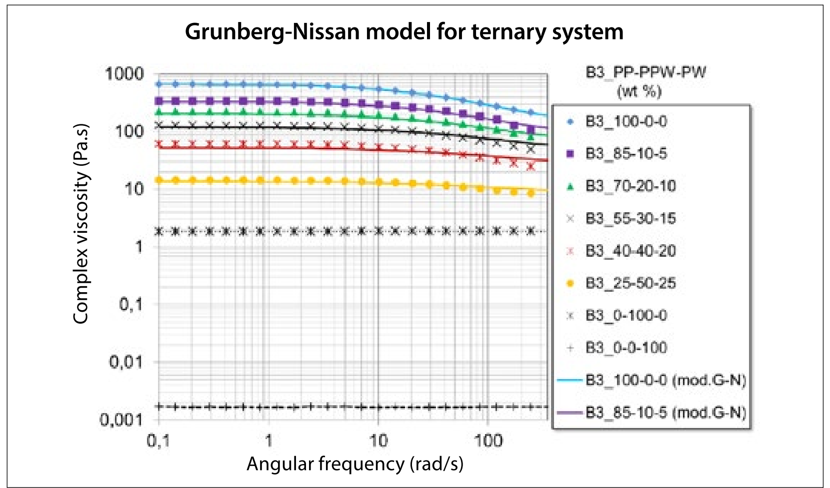

Fig. 14 Calculated (lines) and measured (symbols) viscosity of binders for PIM [11] (Courtesy EPMA)

was best at the gate position and decreased with the distance from the gate. Secondly, and surprisingly, the accuracy of the sintered samples was better than that of the green samples (Fig. 11, left side). The right side of Fig. 11 was interpreted as an ejection effect. Apparently the sample had been deformed by the piston during ejection.

A second topic was raised in Piotter's presentation, namely micro powder in-mould labelling. The process is a variant of macroscopic in-mould labelling. It is capable of applying a functional material on the surface of a microPIM part of complex geometry (Fig. 12). The functional material in powder form is mixed with a low viscosity binder so that it forms a slurry and is then processed by tape casting. Suitable small pieces are stamped out of the resulting tape and inserted into the mould cavity where the injected feedstock presses the tape against a microstructured mould insert. After debinding and sintering the functional material is firmly connected with the substrate material.

Feedstock development based on eco-friendly binder system for Powder Injection Moulding

Carolina Abajo, Universidad Carlos III, Madrid, Spain, reported on the development of eco-friendly binder systems for PIM based on polyethylene glycol (PEG) and cellulose acetate butyrate (CAB).

The advantage of PEG is its solubility in water and its harmlessness to the environment. CAB is a naturally derived product with a zero balance of CO_2 emission when degraded thermally. The molecular weights of PEG and CAB were modified and four different combinations of low and high molecular weight components at a ratio of 70% PEG/30% CAB were investigated. All variants could be processed into mouldable feedstocks with zirconium silicate powder at 57.5 vol-% loading.

The kinetics of solvent debinding were studied in detail. In the first stage the PEG combines with water and tends to swell so that it can destroy the compact if the backbone binder is not strong enough. Then PEG is dissolved in the water and is removed. Finally the compact shrinks when it is dried.

PEG dissolves much faster at 60°C than at 40°C and 50°C (Fig. 13a). After five hours approximately 80% of PEG is removed (Fig. 13b). The molecular weight of the backbone binder (CAB) had no effect on debinding, but the PEG binder with low molecular weight dissolved faster and more efficiently, whereas for PEG with high molecular weight the shape retention was reported as being unsatisfactory.

Rheological behaviour of binder systems for PIM and mixing rules for calculation of viscosity

The prediction of the viscosity of multi-component binder systems based on viscosities of the individual binder constituents for PIM was the subject of research by Christian Kukla from the Industrial Liaison Department, Montanuniversitaet Leoben, Austria. Kukla compared various mathematical models describing the viscosity of a mixture of viscous substances and compared them with experimental results of viscosity measurements on mixtures of polypropylene (PP), polypropylene wax (PPW) and paraffin wax (PW) in various proportions. The best coincidence between model and experiment was found with the modified Grunberg-Nissan equation (Fig. 14).

Analysis of the Influence of assembly force on joint strength during MIM sinter joining

Preliminary results of sinter joining experiments on two green injection moulded compacts was presented by Katharina Klimscha, Institute of Production Science, Karlsruhe Institute of Technology, Germany. Two green samples with rotational symmetry resembling tensile test samples, but with an internal hole, were assembled upright, so that their joining tapers were in contact (Fig. 15). Then the assembled samples went through the debinding and sintering cycle.

A MIM feedstock made of carbonyl iron with 8 weight-% Clariant binder Licomont EK 583 was tested. The effect of the assembling force was systematically investigated and it was found that the green samples could be assembled with a force of up to 6 N without breaking. However, with increasing assembling force the strength of the joint after sintering somewhat decreased. The experiments will be continued stated Klimscha.

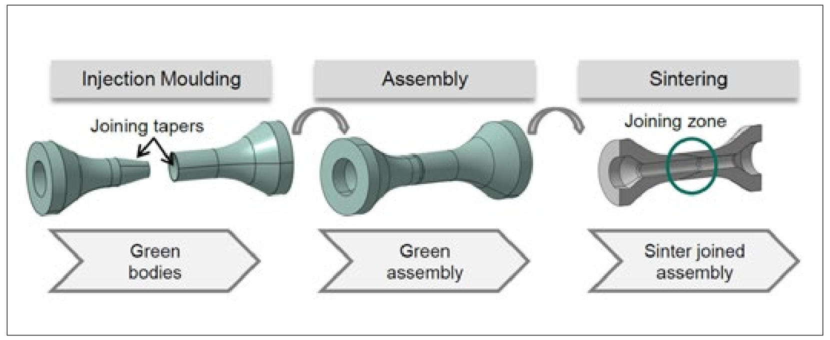

Fig. 15 Geometry of samples for sinter joining experiments [12] (Courtesy EPMA)

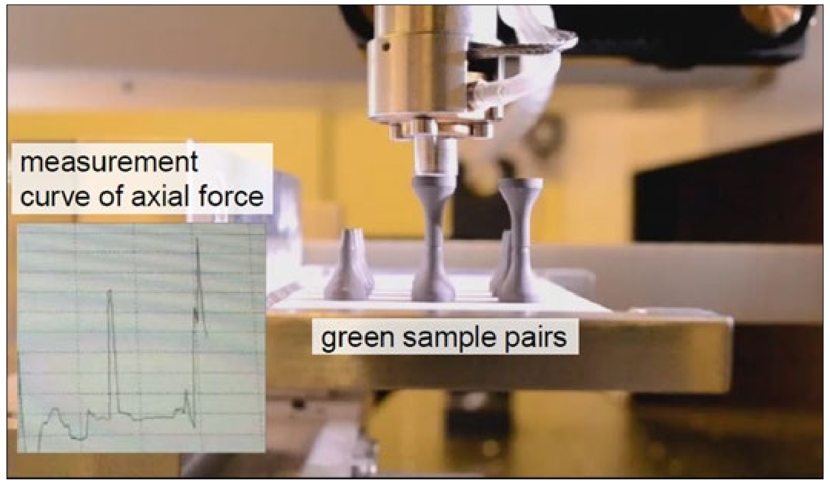

Fig. 16 Automated assembling of green MIM samples with force control [12] (Courtesy EPMA)

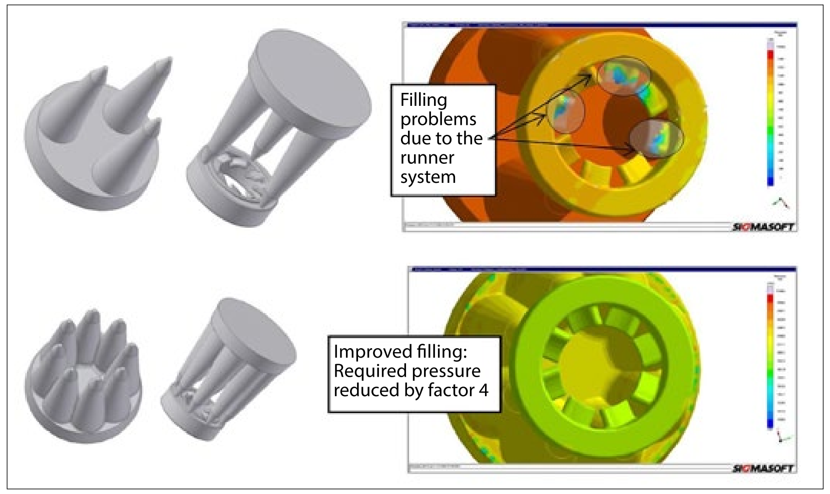

Fig. 17 Computer simulation of mould filling with 3 gates (top) and 8 gates (bottom) [13] (Courtesy EPMA)

Quality and Productivity in Powder Injection Moulding

The contributions to the Special Interest Seminar on PIM were much closer related to actual production than the more scientific presentations in the technical sessions. The aspects of parts production that were considered ranged from computer simulation of the moulding cycle through shape retention, powder-binder separation, choice of raw materials to the qualification of aerospace applications and the calculation of total manufacturing costs.

Micro-moulded CIM components: simulation based mould and process development

Marco Thornagel, Sigma Engineering GmbH, Aachen, Germany, demonstrated the benefits of 3D computer simulation for part and mould design as well as process development of a ceramic micro turbine guide wheel. The guide wheel of just 3.8 mm outer diameter was made from zirconia. The mould manufacture for such a small high precision component is so expensive and time consuming that the first attempt must be successful, otherwise the whole project may fail for cost reasons alone. Modern computer software provides the opportunity to optimise part and tooling design in a realistic simulation.

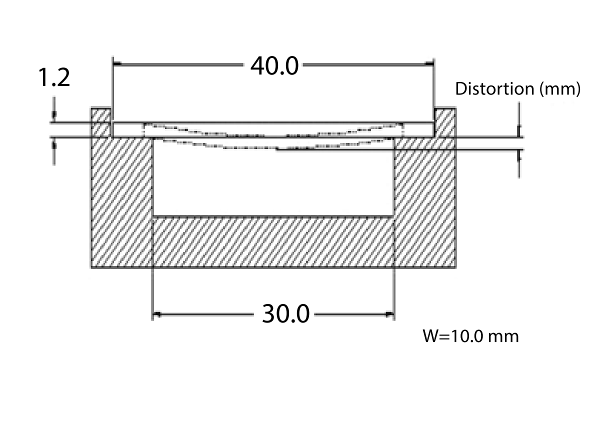

Fig. 18 Test for a quantitative evaluation of shape retention [14] (Courtesy EPMA)

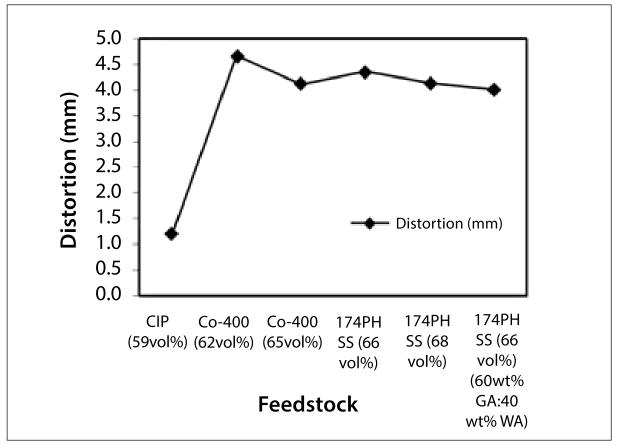

Fig. 19 Distortion of various feedstocks after sintering [14] (Courtesy EPMA)

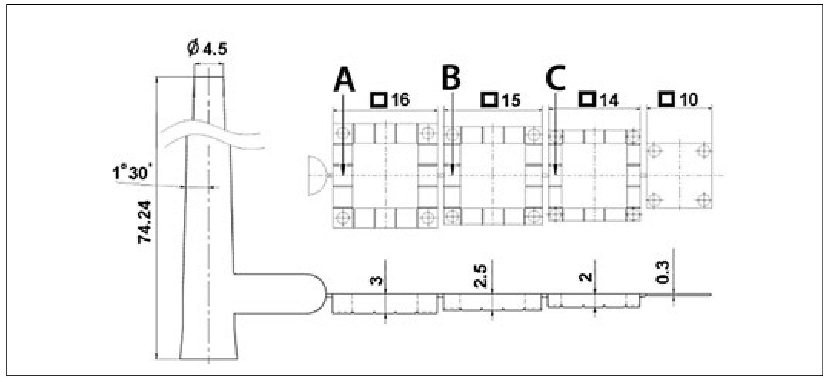

Fig. 20 Test mould for evaluating powder-binder separation [15] (Courtesy EPMA)

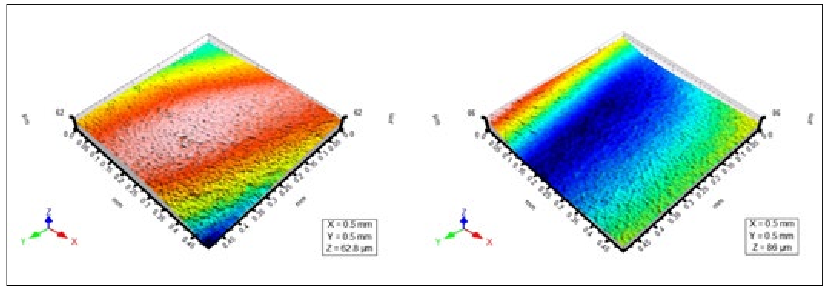

Fig. 21 CLA scanner image of a flawless surface (left) and with powder-binder separation (right) [15] (Courtesy EPMA)

For the successful simulation of the moulding cycle it is necessary to characterise the feedstock and feed a full set of feedstock characteristics into the software. This includes the effect of temperature and shear stress on the viscosity, the thermal conductivity and specific heat capacity. Fig. 17 shows the results of computer simulation for moulding the turbine guide wheel. With three gates the simulation predicted incomplete mould filling, but with eight gates the mould was completely filled and the required pressure was reduced by a factor of four.

Effect of particle spacing on shape retention phenomena in PIM

Shape retention during debinding and sintering is a necessary requirement for PIM feedstocks. A key factor for shape retention is to find the optimum inter-particle spacing or, in other words, the optimum powder loading. If inter-particle spacing is too small, the flow into the mould is inhibited. If it is too large, shape retention decreases. Mukund Bhimsena Nagaraj, Indo-US MIMTec Pvt Ltd, Bangalore, India presented a method to find the optimum inter-particle spacing and a simple test for a quantification of shape retention. In a systematic investigation the effect of inter-particle spacing on shape retention was demonstrated.

The test for the quantitative measurement of shape retention uses flat rectangular samples of 40 x 10 x 1.2 mm (green dimensions) which are placed on a ceramic support as shown in Fig. 18. The deflection after debinding and sintering is measured. Results of distortion measurements are shown in Fig. 19. The meaning of the feedstock designations are as follows:

- CIP (59 vol%): Fe-2% Ni based on carbonyl iron powder, powder loading 59 vol-%
- Co-400 (62/65 vol%): Cobalt base alloy, powder loading 62/65 vol-%
- 174PH SS (66/68 vol%): Stainless steel 17-4PH, powder loading 66/68 vol-%

According to Fig. 19, CIP (59 vol%) feedstock has by far the best shape retention. A comparison between Co-400 (62 vol%) and Co-400 (65 vol%) as well as between 174PH (66 vol%) and 174PH (68 vol%) shows that a higher powder loading leads to better shape retention. Samples with a lower powder loading slumped and could therefore not be evaluated.

Quantitative analysis of surface properties resulting from powder-binder separation

Berenika Hausnerova, University of Zlin, Czech Republic proposed a test method for the quantitative analysis of powder-binder separation in injection moulded green compacts. The experimental part included injection moulding in a test mould with three quadrangular elements denoted as A, B and C, and a thin plate at the end (Fig. 20).

The surface structure of green MIM compacts moulded from three different commercial 316L feedstocks was analysed with a contactless 3D Chromatic Length Aberration (CLA) scanner (Fig. 21). This method is reported to be capable of detecting very minor modifications of the surface structure which are indicative of powder-binder separation.

A mathematical approach was used to calculate a variability parameter of the binder content as a characteristic for powder-binder separation induced by flow phenomena. The feedstocks under investigation exhibited clear differences in the variability parameter.

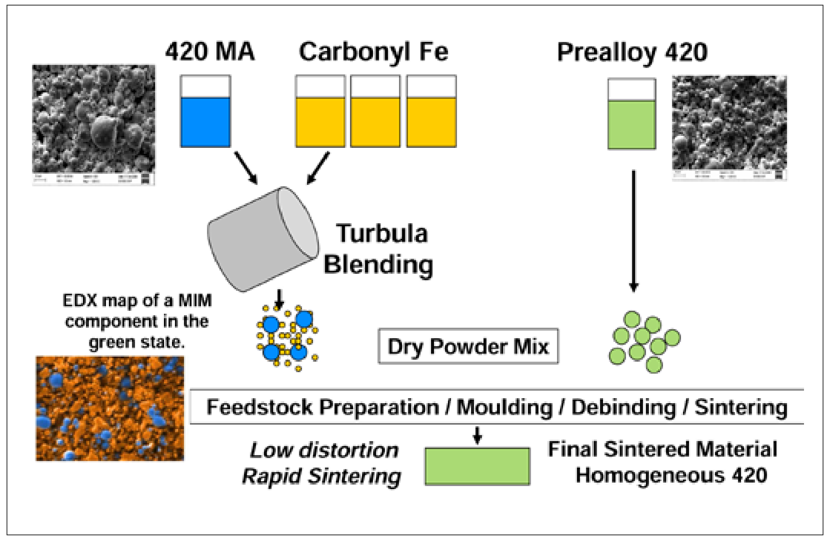

Fig. 22 Comparison of the master alloy and prealloy route [16] (Courtesy EPMA)

Processing and properties of AISI 420 MIM Parts manufactured via prealloy and master alloy routes

An innovative concept of producing MIM stainless steels from gas atomised master alloy powders mixed with carbonyl iron was presented by Keith Murray, Sandvik Osprey, Neath, UK (Fig. 22). The following benefits of this method as compared to prealloyed stainless steel powders were claimed:

- Activated sintering at lower temperatures due to the fine carbonyl iron powder (CIP)
- Higher green strength and better shape retention
- Higher sintered density and mechanical properties
- Low carbon master alloys can be blended with high carbon CIP grades to control carbon level
- Fewer impurities
- Cost savings.

Master alloy powder Fe50Cr LC with a particle size -22 µm was blended with CIP to form a Fe-12% Cr alloy (AISI 420). The comparison was made with a prealloyed gas atomised 420 powder with a particle size -22 µm. Both powders were compounded with a binder from the company TCK, injection moulded, debound and sintered at 1350°C in a N_2 and H_2 atmosphere. Subsequently the steels were heat treated.

The experiments showed that high densities could only be achieved with special control of the sintering atmosphere. The prealloyed powder route is less sensitive to the sintering atmosphere and gives slightly higher densities. The master alloy route leads to significantly higher strength in the sintered condition. Sintering in hydrogen causes carbon loss and higher densities and ductility, but lower strength. With due regard to the requirements for sintering high chromium steels it appears feasible to apply the master alloy concept.

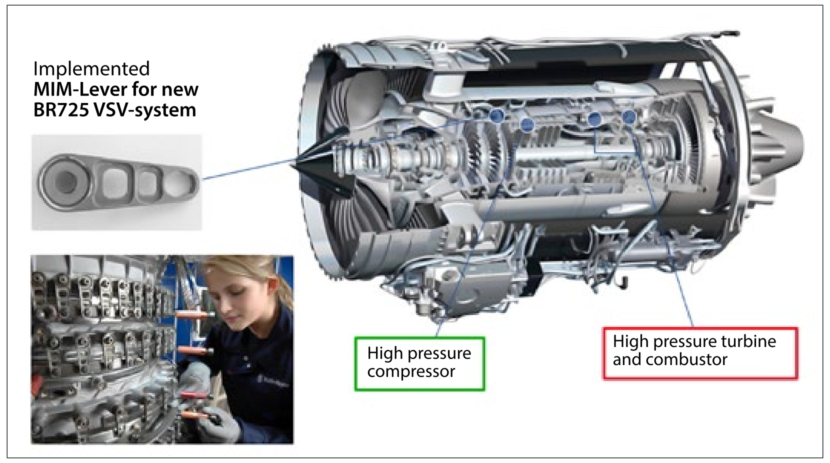

Fig. 23 Existing and potential MIM applications in an aircraft engine [17] (Courtesy EPMA)

Metal Injection Moulding of Inconel 713LC for engine applications

The development of MIM components from Inconel 713LC for aircraft engines was reported by Lukas Schrüfer, Rolls-Royce, Germany from the perspective of the end user. Schrüfer identified one existing application and several potential ones (Fig. 23). Then Schrüfer outlined the path of approval through material validation and component development.

The first requirement set by the industry is material validation. A potential supplier has to establish the manufacturing process, qualify its capability and create a design database. Then he has to prove that the material he produces meets the required specifications.

The evaluation of MIM IN713LC showed that in spite of the 2-5% residual porosity in the sintered material the properties can compete with forged and cast Inconel in tensile strength, creep and high cycle fatigue. The next steps are to investigate the potential for improvement by heat treatment and/or Hot Isostatic Pressing (HIP) and to ensure that the data derived from test samples correlate with the component properties.

Comparative study of costs of powder steel micro manufacturing techniques in a life-cycle perspective

The traditional way of cost calculation for industrial products considers the raw material and manufacturing cost, maintenance cost and disposal or

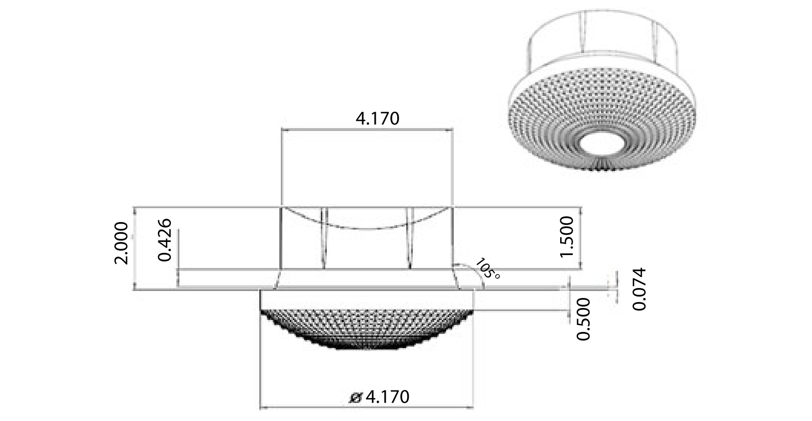

Fig. 24 Light diffuser [18] (Courtesy EPMA)

recycling cost. Life Cycle Engineering, as Elsa Henriques, Technical University of Lisbon, Portugal, explained, is a modern way of starting from the design stage and including not only ecological aspects, but also tool design and the tooling costs, along with all costs incurred during the life cycle of a product. Included in the development stage of the product is an assessment of all costs associated with the design and its life cycle.

'Included in the development stage of the product is an assessment of all costs associated with the design and its life cycle'

A case study of a light diffuser part (Fig. 24) made from PMMA in a production volume of 500,000 parts per year was presented. Two alternatives for the injection moulding tooling were discussed, a conventional micro mould tooling and a more expensive tooling with disposable inserts. The optimum number of mould cavities in the tooling was calculated as a function of the required number of parts per year and the tool life. The conventional mould was more economical for production volumes below 20 million parts and the alternative with disposable easy-to-replace insert was more economical above 20 million parts.

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[17] L Schrüfer, Metal Injection Moulding of Inconel 713LC for Engine Applications, as presented at Euro PM2013, Sweden.
[18] E Henriques, Comparative Study of Costs of Powder Steel Micro Manufacturing Techniques in a Life-Cycle Perspective, as presented at Euro PM2013, Sweden.

Acknowledgements

Euro PM2013 was organised by the European Powder Metallurgy Association. For more information please visit the EPMA website: www.epma.com

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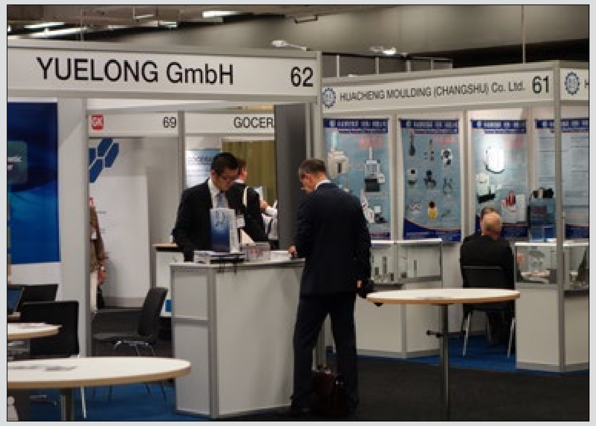
Euro PM2013 gallery

CMG Technologies: The UK's leading MIM producer targets the aerospace, automotive and medical sectors

CMG Technologies was formed following a recent management buyout of the French owned MIM operation Egide UK, based in Rendlesham, Suffolk. Today the business is reported to be thriving after several years of diversifying its markets and enhancing its capabilities with a broad range of advanced materials aimed primarily at the aerospace, automotive and medical sectors. *PIM International's* Nick Williams reports on recent developments at the company.

Despite the UK being home to a number of highly regarded research institutions active in MIM, along with Sandvik Osprey, a world leader in the production of MIM grade gas atomised powders, the country is not widely associated with MIM components production. However, changes in the ownership of one of the UK's leading MIM producers based in the small Suffolk town of Rendlesham, look set to mark a new phase in the growth of MIM technology in the UK.

On November 1st Egide UK, a producer of metal, ceramic and plastic injection moulded components established in 1998, was purchased by its management team from the French parent company Egide SA. The new company, Conway Marsh Garrett Technologies Limited, now trades as CMG Technologies.

Egide UK had successfully operated as part of the Egide SA Group since the French group's acquisition of the business in 2002. In recent years, however, the parent company's business strategy changed and, as a result, there was no longer a requirement for the in-house production of precision MIM hermetic packages and related components for use by Egide SA.

As MIM production for the parent company was reduced, Egide UK's management team successfully diversified production into a range of new markets and in the last two years all MIM production was for third party customers. "During this period of diversification the company achieved significant growth whilst at the same time remaining profitable," stated Chris Conway, Managing Director of CMG Technologies. The company is now the largest MIM operation in the UK.

In addition to Chris Conway, CMG

Fig. 1 CMG Technologies' management team, Chris Conway (left), Phil Marsh (centre) and Rachel Garrett (right)

Fig. 2 A view of part of the PIM production facility at CMG Technologies

Technologies' management team includes Phil Marsh, Technical & Production Director, and Rachel Garrett, Technical Sales & Marketing Director. The three are today the sole shareholders in CMG Technologies.

Chris Conway told *PIM International*, "Becoming CMG Technologies is another milestone in our fifteen year history. Whilst the name has changed, the way we operate and our team of dedicated employees remains the same. Other than the change in name nothing else will change, we will continue to offer the same high level of service and quality that we have always strived to achieve. Our vision is to maintain our position as the MIM market leader within the UK whilst continuing to maintain and expand upon our diverse array of blue chip customers. We also aim to open up new market sectors with the development of new materials, in particular MIM titanium."

CMG Technologies supplies to a number of tier one, blue chip companies such as Strattec Security Systems to whom it supplies a special finish surround for the Aston Martin keyfob, Siemens, Perkin Elmer and Autocruise, part of the TRW Automotive Group. These and other clients operate within an array of industries. The company's main markets, however, are medical, luxury automotive and industrial.

"We have diversified into a number of markets, which gives the business strength and stability particularly when certain markets fluctuate. We don't see this changing as a result of the management buyout," stated Rachel Garrett.

Swann-Morton, a world leader in the manufacture of surgical scalpel blades, handles and disposable scalpels uses CMG, under an exclusivity agreement, to supply almost the complete range of the company's Metal Surgical Handles.

Having the handles manufactured by Metal Injection Moulding has, it was stated, brought many benefits for the client.

Swann-Morton told *PIM International*, "We have always worked very closely with CMG/Egide on the design of the handles to ensure that the parts are optimised for the process. As such, together we have pushed the boundaries of the process as CMG now supply handles to us which are 210mm long. They are also supplying us with a hollow handle which is made up of two parts and then sintered together as one."

"CMG Technologies aren't just a supplier to us, we view them as an extension of our own business. It was a big decision for us to outsource the manufacture of our handles, but it's one we've never looked back on."

Whilst the UK is a key market for the company, more than 40% of CMG Technologies' business comes from overseas. "We are a global supplier with customers in Europe and further afield. We expect this international area of our business to continue to grow in line with UK sales," added Rachel Garrett.

Materials and feedstock

Commenting on the material types processed at CMG Technologies Phil Marsh told *PIM International*, "The most commonly used materials for us are 17-4PH and 316L stainless steels. However, we also process kovar, nickel iron, copper, 100Cr6, iron, magnetic alloys and ceramics, as well as advanced materials such as Hastelloy and Inconel. We always strive to continuously push the boundaries of MIM to keep us ahead of the competition and to enable us to take on a greater range of projects. As a result we have recently developed the ability to process of a number of more exotic materials including precious metals and titanium."

Fig. 3 Once four separate parts, CMG Technologies now produce a net shaped MIM component used within high precision measuring equipment

Fig. 4 Medical Device Component with moulded internal threads

Whilst CMG Technologies produces the majority of its own feedstock in-house, the company also purchases off the shelf feedstock for specific applications. Phil Marsh stated, "We now process parts using BASF's Catamold system as well as mixing our own feedstock. Having both routes is a huge advantage as it covers all possible requirements, gives us a great amount of flexibility and enables us to cost our products as competitively as possible."

Phil Marsh also commented on the advantages that in-house feedstock production can offer. "Creating feedstock in-house allows us to finely tune the material to meet specific tolerance and surface finish requirements. This enables us to produce parts of very high quality and precision. Where necessary we use much finer powders than typically found in off-the-shelf feedstock, as well as irregular or spherical powders, which help us to achieve better densities, distinctly improved surface finishes and tighter tolerances. Using the Catamold system does however also have its advantages as it's excellent for larger parts with thicker sections or where a more rapid cycle time is required."

He added that the ability to manipulate powder to binder ratios to control the shrinkage of a part has enabled their specialists to change materials used for a specific tool without having to make expensive tool modifications. This, it was suggested, is particularly helpful when customers have to move business to CMG Technologies from another supplier, allowing for very short lead-times and avoiding the need for costly tool modifications.

Titanium MIM at CMG Technologies

A number of titanium MIM products are under evaluation at CMG Technologies. The technical developments for the company's titanium process were achieved through a joint collaboration with Johnson Matthey and Sheffield University. The company prepares its feedstock through mixing titanium powder with its own binder system, enabling it to achieve an excellent surface finish of around RA 0.6 and a high density of around 95%. The MIM titanium parts that are produced meet the ASTM grade for MIM Ti6Al4V for surgical implant applications.

Chris Conway told *PIM International*, "There are many applications for MIM titanium including weight saving components for the aerospace and automotive industries and biocompatible products for the medical sector where the material's strength and durability are also an advantage. However, as titanium is a highly priced commodity these benefits can come at a cost. By choosing MIM as the route of manufacture, customers have the distinct advantage of having the ability to produce a net shaped component with no wastage, therefore reducing their costs significantly."

CMG Technologies is currently working on a project with a medical company to make titanium components

Fig. 5 CMG Technologies produces these surgical scalpel handles for Swann-Morton (Photo courtesy Swann-Morton)

'By choosing MIM, customers have the distinct advantage of having the ability to produce a net shaped component with no wastage, therefore reducing their costs significantly'

Fig. 6 Two separate MIM components locked together with a bayonet connection used within the Telecoms market

Fig. 7 Intricate internal details achieved for Gripple's wire joiners used for agricultural and construction applications

for implantation. Due to the restrictions of the product's current method of manufacture, the geometry of the part had been simplified at the expense of its functionality. Chris Conway stated, "Our customer has redesigned the product taking advantage of MIM's capabilities. This has allowed us to produce a competitively priced, highly complex component which includes features that couldn't be achieved through traditional routes of manufacture but will have multiple benefits to the implant patient giving them a better quality of life."

'Our customer has redesigned the product taking advantage of MIM's capabilities. This has allowed us to produce a competitively priced, highly complex component..'

Production facilities

The company currently operates six Arburg moulding machines, six debinding ovens and four sintering furnaces and employs a staff of 30. Phil Marsh stated, "We have recently invested in a fifth sintering furnace which once commissioned will increase our capacity for production parts, as well as freeing up space for development projects and enabling us to sinter titanium in-house. We work with customers on projects of various volumes ranging from as few as 500 components a year up to 500,000 a year, but with our expansion we have the capacity to meet the needs of quantities into the millions."

As well as outsourcing some tooling production to highly competent UK based tooling companies CMG Technologies also has its own in-house tool room. "Not only does our tool room produce tools of exceptionally high standards, they also produce a variety of jigs and fixtures which help ease and improve production, which in turn increases our yields and quality standards," added Phil Marsh.

"By having our own tool room we are also able to offer quick turnarounds for design modifications and offer expert advice on ways to optimise parts for our MIM manufacturing route. Another benefit is the fact that if customers have existing tooling which they want to move across to us, we can quickly service and modify the tooling for our machines without the need for costly new tooling investments. This was particularly helpful to the customers of Metal Injection Mouldings Ltd in Altrincham (UK) because when that business closed they advised their customers to transfer their tooling to us. In such cases we could be a continued source of supply with minimum delay and cost."

The tool room is also experienced at producing prototype tooling with a very short lead-time and relatively low cost. "This is a major benefit if a project has tight time to market timescales. Our customers can have a MIM product in their hand within a matter of weeks to help keep their projects moving quickly," stated Phil Marsh

Commenting on the outlook for MIM manufacturing in the UK, Rachel Garrett told *PIM International*, "We take a lot of pride in the fact that we are a UK based manufacturing company with all operations taking place in one location in Suffolk. We have seen a clear move by companies deciding to "reshore" their purchasing activities back into the UK and Europe. Now that we are a stand-alone British company we hope to help support this even further by giving companies a route to source high quality, complex components at a competitive price, overcoming rising overseas production and shipping costs, simplifying transport and logistics whilst at the same time reducing their carbon footprint."

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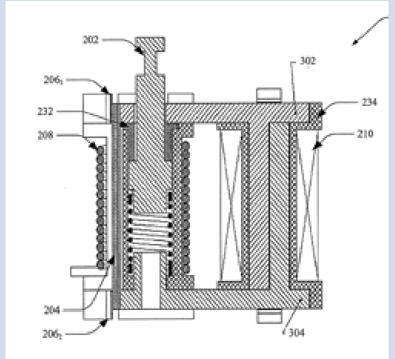
Global PIM Patents

The following abstracts of PIM-related patents have been derived from the European Patent Organisation databases of patents from throughout the world.

US2011267722 (A1)
COST EFFECTIVE DESIGN FOR A CURRENT TRANSFORMER WITH AN INTEGRATED MAGNETIC ACTUATOR
Publication date: 2011-11-03
Inventor(s): Annis Jeffrey, et al., Rockwell Automation Tech Inc., USA

This patent discusses a system comprising of a magnetic actuator, a current transformer and operational electronics in a dual-coil circuit breaker. The system includes an inline, but non concentric, implementation of the primary and secondary coils to maintain a narrow width suitable for retrofitting in standard industrial rack mounted enclosures. The system further comprises a split core design that is integrated into an upper and lower plate which slide together and are retained by a secondary coil bobbin. Typically, the two parts of the split core can be manufactured into net shapes by utilising a powder metal or Metal Injection Moulding process. Moreover, the split core design disclosed can reduce costs and time associated with manufacturing and assembly of the current transformer.



WO2011125900 (A1)
SINTERED MAGNET AND METHOD FOR MANUFACTURING SINTERED MAGNET
Publication date: 2011-10-13
Inventor(s): Morita Hiroyuki, et al., TDK Corp, Japan

Disclosed in this patent is a method for manufacturing a sintered ferrite magnet. The magnet is manufactured by firstly producing a compact by injection moulding a magnetic powder mixture obtained by mixing magnetic powder and a binder resin in a mould to which a magnetic field is applied. The compact is then sintered. The thickness in the position of the centre of gravity of the sintered magnet is 3.5 mm or less. The surface roughness (Rz) of the sintered magnet is 0.1-2.5 [mu]m inclusive. The surface roughness (Rz) is a ten-point average roughness.

US2011226439 (A1)
MULTI-COMPONENT COMPOSITION METAL INJECTION MOULDING
Publication date: 2011-09-22
Inventor(s): Miller James D, et al., Cool Polymers Inc, USA

A method of Metal Injection Moulding using an injection moulding machine having a heated barrel with an increasing temperature gradient is disclosed in this patent. A first step includes providing a metal alloy feedstock including a first component having a first melting point and a second component having a second melting point that is higher than the first melting point. The first melting point and the second melting point are selected to match the temperature gradient of the heated barrel of the injection moulding machine.

A second step includes feeding the metal alloy feedstock into the injection moulding machine. A third step includes melting the metal alloy feedstock within the heated barrel of the injection moulding machine. A fourth step includes maintaining the percentage of solids to liquids in the metal alloy feedstock of the first component and second component within a processable range of about 5% to about 30%.

CN102225574 (A)
INJECTION MOULDING METHOD OF TEMPERATURE SENSITIVE FERRITE
Publication date: 2011-10-26
Inventor(s): Jianjun Tian, et al., Beijing Science & Technology University, China

The invention belongs to the field of permanent magnetic materials, and relates to an injection moulding method of a temperature sensitive ferrite.

The method comprises of mixing temperature sensitive ferrite powder with a paraffin-based adhesive system, wherein the temperature sensitive ferrite powder consists of 50 to 60% of Fe_2O_3, 15 to 30% of ZnO and 10 to 25% of Mn_3O_4 serving as main body components (in molar ratio) and 0.5 to 2.5% weight of additive, and the carrying capacity of the ferrite powder is 45 to 65% volume.

The mixture is mixed for 0.5 to 3 hours at the temperature of between 80 and 180 C, and then the mixture is crushed into granular feed. The feed is injected into a die to obtain a moulded blank under the conditions that the injection temperature is 90 to 180 C and the injection pressure is 70 to 100MPa.

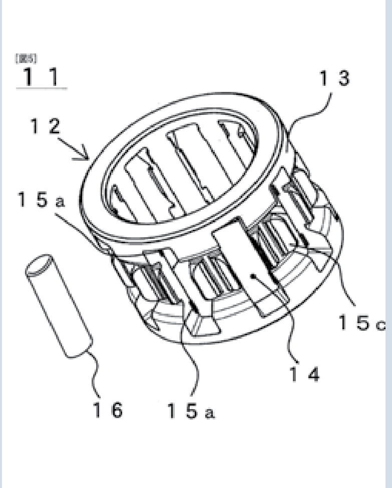
The formed blank is soaked in an n-heptane or trichloroethylene solvent at 20 to 60 C, debinding the blank for 3 to 12 hours before removing and drying the blank. The blank is heated to the temperature of between 450 and 800 C from room temperature at the speed of 0.2 to 3 C per minute, removing the residual adhesive, before sintering the blank for 0.5 to 6 hours at the temperature of between 1,100 and 1,500 C to obtain the temperature sensitive ferrite.

The described method is particularly suitable for preparing and mass producing thin-walled micro temperature sensitive ferrite parts with complex shapes. The prepared product has high dimensional precision, uniform tissue and excellent performance.

WO2011145693 (A1)
ROLLING BEARING AND METHOD FOR PRODUCING SAME
Publication date: 2011-11-24
Inventor(s): Matsuo Akira, et al., NTN Toyo Bearing Co Ltd, Japan

Discussed in this patent is a rolling bearing capable of stabilising and retaining rolling elements and reducing production cost, while being excellent in strength, stiffness, thermal resistance, and dimensional accuracy without sacrificing performance as a bearing. Also provided is a method for producing the same.

The rolling bearing uses a retainer that has a number of pockets that accommodate and retain the rolling elements in the circumferential direction of the peripheral wall of a cylinder-shaped member separated by prescribed intervals. The retainer is integrally formed by Metal Injection Moulding and is provided with a rolling element-accommodating area. A structure for preventing the rolling elements from falling out is formed by compressing the outer periphery of the rolling element-accommodating area in the direction from the outer surface of said retainer toward the radial centre.



CN102172960 (A)
POWDER INJECTION MOULDING METHOD FOR SILICON CARBIDE CERAMIC SAND-BLASTING NOZZLE
Publication date: 2011-09-07
Inventor(s): Zhen Lu, et al., Harbin Institute of Technology, China

The invention discloses a Powder Injection Moulding manufacturing method for a silicon carbide ceramic sand-blasting nozzle. This patent aims to address the problems of the existing complicated method for manufacture, high production costs and low efficiency.

The method comprises the steps of preparing a feed, preparing injection blanks, preparing blanks and placing the blanks in a sintering furnace for sintering followed by grinding and polishing, thus obtaining the silicon carbide ceramic sand-blasting nozzle. The silicon carbide ceramic sand-blasting nozzle manufactured in the invention has good wear resistance, the compactness can reach over 98% through tests, the pore path of the sand-blasting nozzle is small and has the diameter of 0.5-3.0mm, the internal smoothness of the pore path is good, the blasting effect is ideal, the draw ratio can achieve (50-150). The production efficiency is high and the cost is low. The method is applicable to manufacturing pure-carbonisation silicon carbide adding additives, and silicon carbide composite sand-blasting nozzles with low cost in bulk.

Influence of processing on the properties of IN718 parts produced via Metal Injection Moulding

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The Ni based superalloy Inconel 718 (IN718) is widely used in high temperature applications, nuclear and petrochemical industries due to its high strength at elevated temperatures, oxidation resistance and heat corrosion resistance. In this study, IN718 compacts were fabricated using the Metal Injection Moulding (MIM) technique. Standard tensile bars were produced and then subjected to room temperature and high temperature mechanical tests at 650°C. A selected number of samples were also subjected to hot isostatic pressing (HIP), solution treatment and precipitation ageing. Assessments of the chemistry, tensile properties and fracture surfaces after mechanical testing were carried out. The chemical composition in the final heat treated samples was found to meet the requirements of the AMS 2269 standard. The final room temperature mechanical properties of the MIM IN718 samples were above the AMS 5383 (Cast), AMS 5662 (Wrought) and the AMS 5917 (MIM) standards to which they were compared. The results of the elevated temperature mechanical properties in the HIPped state were also all above their AMS cast, wrought and MIM equivalents, except for the 0.2 proof stress. After heat treatment the mechanical properties at 650°C were superior to the AMS equivalents. The fact that the elongation of the samples without HIP in the final heat treated samples also surpassed the MIM standard AMS 5917 showed that, where the Metal Injection Moulding process is controlled carefully, the consolidation of the MIM samples through HIPping process can be omitted to reduce costs.

Introduction

Superalloys are heat-resisting alloys based on nickel-iron or cobalt exhibiting a high strength at elevated temperatures, satisfactory oxidation resistance and heat corrosion resistance. These properties make them suitable for many uses in high temperature applications, automotive, medical, chemical, and petrochemical industries, but their high strength and toughness make them difficult to shape via machining or forging [1].

Inconel 718 is one superalloy that is used extensively in high temperature applications, nuclear and petrochemical industries due to its high tensile strength and resistance to fatigue as well as oxidation at elevated temperatures [2]. IN718 is primarily strengthened by γ” precipitates (Ni_3Nb) and γ’ ($Ni_3(Al,Ti)$) intermetallic compounds with bct and fcc crystal structures, respectively, in γ-fcc austenitic matrix [3] [4]. Another prominent phase found in this alloy is the δ (Ni_3Nb) with an orthorhombic crystal structure. It does not contribute to alloy strength but is found to be desirable for grain size control and improvement of stress rupture ductility [5, 6].

IN718 is processed via forging and also through the conventional Ingot Metallurgy (IM) route. However, elemental segregation and formation of undesirable phases such as laves, freckles and white spots combined with low dimensional tolerance and rough surface are the serious problems encountered [7-10]. Elimination of these casting defects from IN718 is a time consuming and expensive process [11]. In order to overcome these limitations, processing of IN718 via Powder Metallurgy and Metal Injection Moulding routes offers solutions to these problems [12].

MIM is derived from Powder Injection Moulding. The Powder Injection Moulding process involves combining fine metal, ceramic or carbide powders with a binder which allows the material, known as a feedstock, to be injected into a mould using standard plastic injection moulding machines. The binder is then removed by solvent and thermal processes and the resultant part is sintered at temperatures great enough to bind the particles but not melt the metal, ceramic or carbide material. The sintered compacts undergo some shrinkage, typically to >95% of the pore-free density. Occasionally, the density of the sintered parts is improved by hot isostatic pressing (HIP or HIPping) [13].

The work reported here aims to improve IN718 processing via MIM and produce net shaped components which are suitable for high temperature applications. The optimisation of the MIM process in order to reduce costs by eliminating the hot isostatic pressing step is also reported.

Experimental techniques

The particle size distribution of the the IN718 powder used in this study is shown in Fig. 1. The graph in Fig. 1 shows the particles to be below 20 µm at the 90% cumulative volume level. This is in agreement with the datasheet provided by the manufacturer.

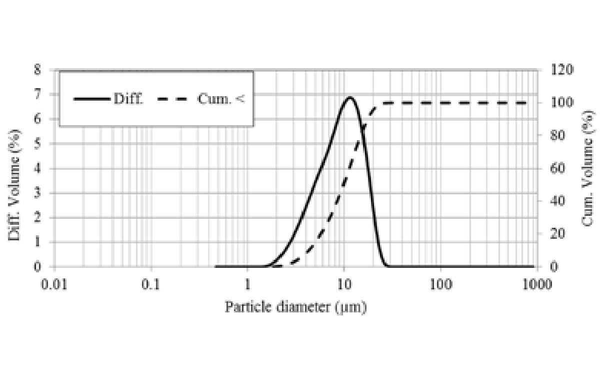

Fig. 1 Powder distribution graph of the IN718 powder

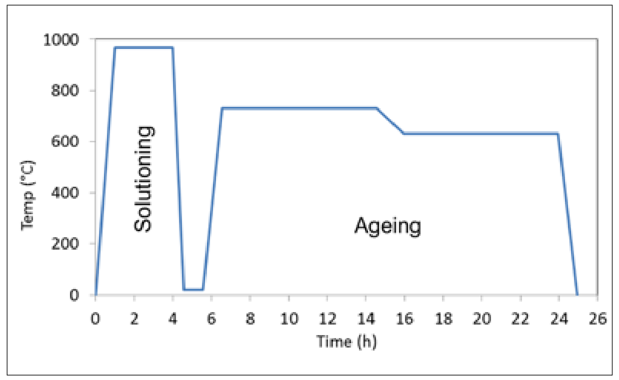

Fig. 3 Chart showing the heat treatment cycle in MIM IN718

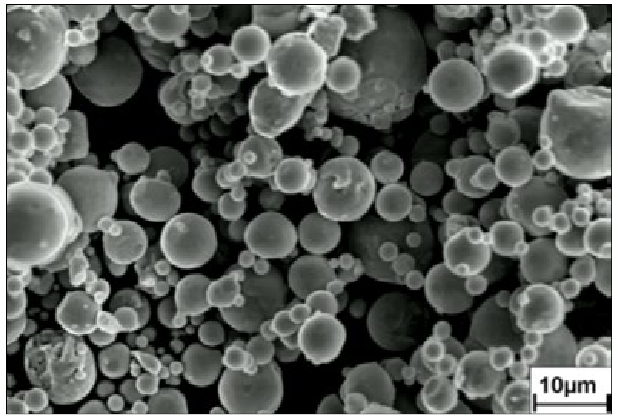

Fig. 2 SEM morphology of the IN718 powder

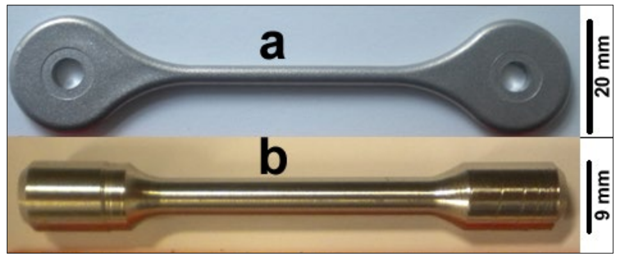

Fig. 4 Sintered test samples. a – MPIF and b – machined BS EN 6892

The morphology of the IN718 powder used in this study is shown in Fig. 2. The powder is largely spherical. Fig. 2 shows that the amount of satellites (smaller particles) present in the powder is relatively low and with no elliptical particles. This ensures good packing and a more consistent behaviour.

The powder was mixed with binder to make feedstock. The mixed IN718 feedstock was granulated and then injection moulded in a 60 tonne Arburg 360C injection moulding machine. Different mould cavities were used. Mouldings were made of MPIF Standard tensile pieces, cylinders for elevated temperature sample machined to BS EN 6892 test samples.

All the IN718 parts were then subjected to solvent debinding followed by thermal debinding and sintering. Sintering was carried out at a heating rate of 10°C/min and then holding at 1270°C for 2 hours. After sintering, a selected number of samples were sent for Hot Isostatic Pressing (HIPping). The HIPping was carried out at a temperature of 1160°C, pressure of 103 MPa for 180 minutes. After HIP, heat treatment was then carried out in the Centorr VI. The specimens were solution treated at 968°C for 3 hours and furnace cooled to room temperature, then aged at 730°C for 8 h, furnace cooled to 630°C at a cooling rate of 56°C/h, and then aged for 8 h and furnace cooled according to SAE AMS 5917-2011 (Metal Injection Molded Nickel Based Alloy 718 Parts Hot Isostatically Pressed, Solution and Aged) [14]. Fig. 3 is a chart showing the heat treatment cycle for the MIM IN718.

Element	AMS 5917 (powder)		Gas atomised IN718 Powder	MIM IN718	
wt%	min.	max.		Solutioned	Aged
Al	0.2	0.8	0.51	0.48	0.56
Si		0.35	0.18	0.19	0.25
Ti	0.65	1.15	0.94	0.87	0.89
Cr	17	21	19.14	18.58	18.78
Fe	Bal.	Bal.	18.79	18.02	18.41
Co		1	0.06	0.05	0.05
Ni	50	55	52.18	52.04	52.08
Mn		0.35	0.17	0.13	0.14
Nb	4.75	5.5	4.96	5.06	5.02
Mo	2.8	3.3	3.1	3.02	3.06
C		0.08	0.05	0.06	0.08
N		0.02	-	0.07	0.068
O		0.06	-	0.12	0.1

Table 1 Chemical composition of the IN718 powder, sintered and heat treated MIM IN718

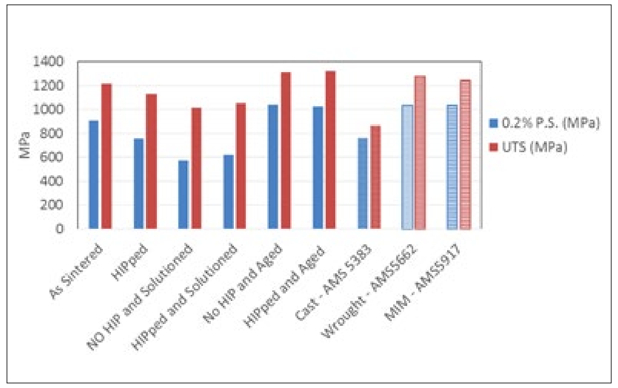

*Fig. 5 The effect of heat treatment on the room temperature mechanical properties (UTS and 0.2 PS) of MIM IN718 tensile test pieces. (*AMS 5662 specified for Bars, Forgings, and Rings)*

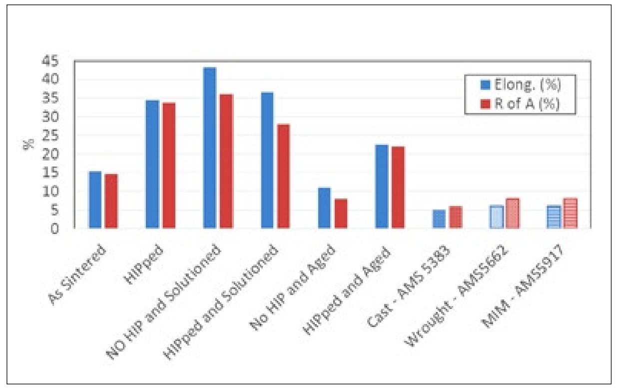

*Fig. 6 The effect of heat treatment on the room temperature mechanical properties (Elong. and R. of A.) of MIM IN718 tensile test pieces. (*AMS 5662 specified for Bars, Forgings, and Rings)*

The tensile samples were then subjected to mechanical tests at room temperature as well as at the elevated temperature of 650°C. Testing was carried according to ASTM E8 and ISO 6892 standards respectively by NDT Ltd (Sheffield, UK).

Mechanical properties of the IN718 parts after testing were compared to standards: (i) SAE AMS 5383 Cast IN718 Specifications, (ii) SAE AMS 5662 Wrought IN718 Specifications, Bar Annealed and Aged and (iii) SAE AMS 5917-2011 Metal Injection Molded Nickel Based Alloy 718 Parts Hot Isostatically Pressed, Solution and Aged. The fracture surfaces of the mechanically tested samples were analysed using Scanning Electron Microscopy (SEM). A selected number of samples were then sectioned, polished and also etched before being analysed using optical microscopy and SEM.

Samples were also analysed for chemical composition after sintering and heat treatment. The chemical composition analysis was carried out using Leco and X-Ray fluorescense (XRF) techniques by London & Scandinavian Metallurgical Co Ltd (Rotherham, UK).

Results

As it was mentioned earlier, mouldings were made of MPIF Standard tensile pieces and cylinders for elevated temperature sample machined to BS EN 6892 test samples. Fig. 4 shows photographs of sintered test samples, with (a) as sintered MPIF and (b) HIPped and machined BS EN 6892. Good shape retention is illustrated in the sintered sample.

The result of the chemical composition analysis of the powder is shown in Table 1 and this was found to conform to SAE AMS 2269 specifications on chemical analysis limits. Also shown in Table 1 are the results of the bulk chemistry of MIM IN718 after solution treatment and after precipitation ageing. It can be see that the MIM IN718 chemical composition is not affected by the MIM and heat treatment process. As it can be seen from Table 1, the maximum oxygen levels in the final samples exceed those of SAE AMS 5917. It is always expected that there will be oxygen pickup during sintering in MIM but controls on oxygen content are critical in order to avoid degrading the ductility. It has been reported that the levels of oxygen that are detrimental to elongation are in the region of 0.2 wt. %. [15].

Furthermore, results of three as sintered samples (not included in Table 1) that were subjected to chemical analysis showed that the carbon content was 0.069, 0.072 and 0.09 wt%. The starting powder carbon content was 0.05 wt %. The carbon pickup is due to the polymer used in the binder material. However this pickup is limited and not detrimental to the final parts because the maximum content of carbon specified for IN718 is 0.08 wt%. A composition variation of +/- 0.01% is permitted as outlined in the SAE AMS 2269 standard.

Mechanical Properties

Fig. 5 shows results of the mechanical properties of the IN718 tensile test pieces after sintering and after the various heat treatment regimes as outlined in the Experimental Techniques section. Fig. 5 shows the effect of heat treatment on the room temperature tensile strength and 0.2% proof stress (UTS and 0.2 PS respectively) of MIM IN718 tensile test pieces.

In the as-sintered state, the UTS and 0.2% proof stress were found to be higher than the cast- equivalent IN718 alloy and inferior to wrought and AMS 5917 MIM equivalent alloys properties. However after precipitation ageing, the UTS and the 0.2% proof stress were higher than the cast, wrought and MIM 5917 equivalent properties, in both HIPped and non-HIPped states.

The evolution of the UTS and the 0.2% proof stress is such that when sintered at 1270°C, the content of liquid phase increases with the sintering of the super-solidus liquid phase taking place. When sintering at 1270°C, the Ni_3Nb phase precipitates and resolves in the solid phase [10]. In the as-sintered state the volume of precipitates pinned to the grain boundaries is not high enough to result in adequate mechanical properties.

After HIPping, the UTS and 0.2 proof stress are seen to decrease. This can be attributed to the grain growth in the alloy because the samples were HIPped at 1160°C. It has been reported that when the HIPping temperature is much higher than the precipitation temperature of γ″ phase and γ′ phase (550-900°C), the strengthening phase precipitates in the γ matrix, and is not found in grain boundaries. This reduces the strength [10].

The UTS and 0.2% proof stress were found to be degraded further after solution treatment, in both the HIPped and in the non-HIPped state and this can be attributed to the dissolution of major strengthening phases during the solution treatment [15]. However after precipitation ageing the UTS and 0.2 proof stress were increased because the γ″ and γ′ strengthening phases were formed.

Fig. 6 shows the effect of the heat treatment on the room temperature mechanical properties, elongation and reduction of area (Elong. and R. of A. respectively), of MIM IN718 tensile test pieces. The elongation of the MIM IN718 was increased after HIPping due to the increase in density. The high temperature and

Sample (Test temp. – 650°C)	0.2% P.S. (MPa)	UTS (MPa)	Elong. (%)	R of A (%)
ISO 6892-5 - HIPped	793	1000	10	17
ISO 6892-5 - HIPped HT	897	1086	8.08	9
Cast - AMS 5383	827	931	6	6
Wrought – AMS 5662	862	1000	6 to 12	8 to 15
MIM – AMS 5917	827	931	6	6

*Table 2 The results of the typical elevated temperature (tested at 650°C) mechanical properties of MIM IN718 tensile test pieces (*AMS 5662 specified for Bars, Forgings, and Rings)*

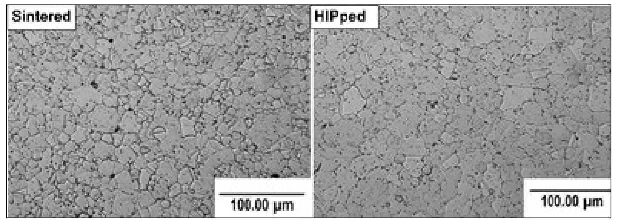

Fig. 7 Optical micrographs showing the evolution of grain sizes in as sintered sample and HIPped MIM IN718

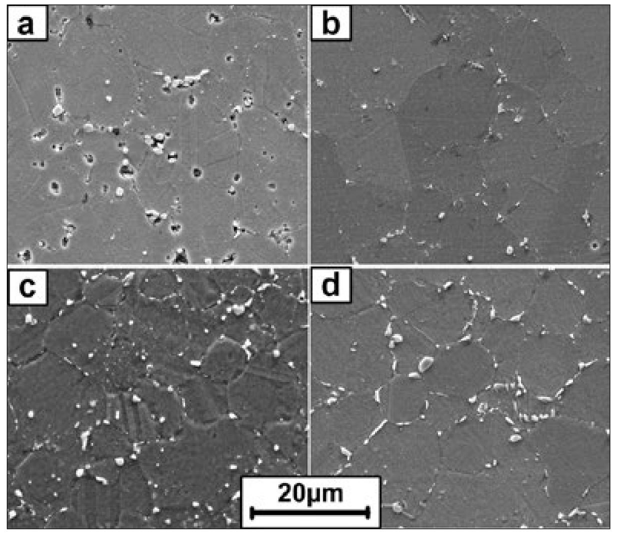

Fig. 8 SEM showing the evolution of microstructure in (a) as sintered sample, (b) HIPped, (c) After solution treatment and (d) after precipitation ageing of MIM IN718

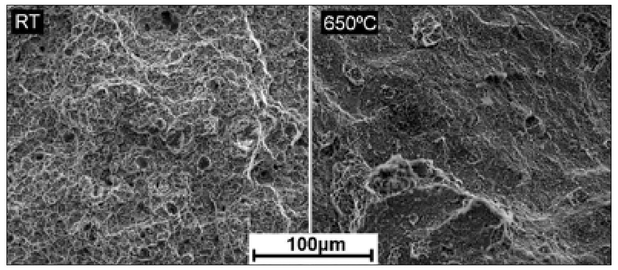

Fig. 9 SEM fractographs of as-sintered IN718 MIM sample at room temperature (RT) and HIPped MIM IN718 at elevated temperature (650°C)

high pressure, grain displacement and plastic deformation associated with the HIPping process improves the density by eliminating the pores, and therefore improves the elongation [10]. The density of the as-sintered sample was found to be ~98% and after HIPping this was ~100%. Whereas the elongation in the as-sintered samples was found to be lower than in HIPped samples, the values of the elongation were found to be well above the cast, wrought and MIM AMS standards equivalents. This can be attributed to the carefully controlled Metal Injection Moulding process which included the optimised moulding temperature, debinding and sintering process. In particular, the sintering process took place in the liquid phase at 1270°C after a carefully selected heating rate and optimum hold time. In liquid phase sintering, the pores are reduced because the liquid phase flows into the pores, leading to the rearrangement of particles. It can also be deduced from Fig. 6 that the higher oxygen levels obtained in Table 1 were not detrimental to the MIM IN718 ductility.

The elongation and the R. of A. were seen to increase dramatically after the samples had undergone solution treatment as a result of the inter-diffusion of elements. It is also thought that the disruption of particle boundary films enhanced bonding between the particles [15]. After the precipitation treatment the elongation stabilised by lowering, but not detrimentally because the values remain above the AMS standard requirements. The lowering of the elongation and R. of A. after precipitation ageing can be attributed to planar slip mechanisms (dislocations) after the formation of the γ'' and γ' strengthening phases.

Table 2 shows the results of the typical elevated temperature mechanical properties of MIM and HIPped IN718 BS EN ISO 6892 tensile test pieces. The results of the elevated temperature mechanical properties before undergoing heat treatments were all above their AMS equivalents, except for the 0.2 proof stress. After solution and precipitation ageing heat treatment, the UTS and the 0.2 proof stress at the elevated temperature were improved by the presence of a larger volume of γ'' and γ' precipitates and the mechanical properties at 650°C were superior to the AMS equivalents.

Microstructure

Fig. 7 shows the effect of HIP treatment in MIM IN718 components. The optical micrographs in Fig. 7 show the complete elimination of pores from within the MIM IN718 samples that were sintered at 1270ºC after HIPping. There are dark particles seen at the triple points of the grain boundaries and these are thought to be oxides and MC carbides. Comparison of the as-sintered and the HIPped micrographs shows that there is an increase in grain size after HIPping from an average of about 10 µm to 15 µm.

Fig. 8 contains four SEM micrographs which show the evolution of microstructure of MIM IN718 during the heat treatment procedures described above. Fig. 8 (a) shows the morphology of IN718 in the as sintered state. The micrograph shows that the secondary phases are distributed uniformly and are present within the grains as well as along grain boundaries. Also visible on the micrograph are residual pores. Fig. 8 (b) shows the MIM IN718 after HIP and the secondary phase precipitates have been reduced in volume overall. The residual pores have also been eliminated as expected. The morphology of MIM IN718 after the solution treatment is shown in Fig. 8 (c). It can clearly be seen that the secondary phase precipitates have increased in volume compared to the HIPped condition and are mostly found at the grain boundaries and inside the grains. The extent to which the solution treatment dissolved the precipitates is illustrated in Fig. 8 (c). After precipitation ageing, the morphology shows precipitation of the secondary phases confined to the grain boundaries as shown in micrograph (d).

Fig. 9 shows SEM fractographs of MIM IN718 samples without the solution and precipitation ageing treatments. The fracture surface of the as-sintered specimen after mechanical tests at room temperature (RT) shows a few particle boundary facets and a lot more areas of fine dimples. The elongation of the as sintered samples was found to be lower at 15% but still exceeding the requirement of AMS standards. The fractograph of the sample at 650°C reveals no particle boundary facets because the samples were HIPped. However the elevated temperature elongation was lower at 8%. From the fracture surface micrograph at 650°C, it can be concluded that the fracture occurred at the precipitate interfaces [16].

Conclusions

IN718 specimens were successfully made via the MIM process. A sintered relative density of ~98% was obtained after sintering samples at 1270°C, and a near full density was achieved after HIPping. The tensile strength and the yield strength at room temperature decreased after HIP and solution treatment whilst the elongation increased. After the precipitation ageing heat treatment, the yield strength and the tensile strength were increased and the elongation was decreased as expected because of the γ'' and γ' phases. The final mechanical properties of the MIM IN718 samples were above all the AMS standards to which they were compared as shown in Fig. 5 and Fig. 6. The fact that the elongation of the samples in the final heat treated samples also surpassed the MIM standard AMS 5917 [14] suggests that where the Metal Injection Moulding process is optimised, as in this case, the HIPping process can be eliminated to reduce costs. The results of the elevated temperature mechanical properties in the HIPped state were also all above their AMS equivalents, except for the 0.2 proof stress. After heat treatment the mechanical properties at 650°C were superior to the AMS equivalents.

Acknowledgements

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Events Guide

2014

PM14 - International Conference on Powder Metallurgy and Particulate Materials & Exhibition
January 23-25, Chennai, India
www.pmai.in/pm14

MIM 2014
February 24-26
Long Beach, California, USA
www.mpif.org

10th International Conference on the Science of Hard Materials (ICSHM10)
March 10 - 14
Cancun, Mexico
www.icshm10.org

PM China 2014 - International Power Metallurgy Exhibition & Conference
April 27-29,
Shanghai, China
www.cn-pmexpo.com

PM2014 World Congress
May 18–22
Orlando, Florida, USA
www.mpif.org

Additive Manufacturing with Powder Metallurgy
(co-located with PM2014 World Congress)
May 18–20
Orlando, FL, USA
www.mpif.org

HIP 2014, 11th International HIP Conference
June 9 -13, 2014
Stockholm, Sweden
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August 24-28 Dresden, Germany
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